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ALBERTA RANGELAND ASSESSMENT USING REMOTELY SENSED DATA

R. J. Brown, F. J. Ahern, K. P. B. Thomson, K. Staenz, J. Cihlar, C. M. Pearce and S. G. Klumph

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SUMMARY

In 1980, the Canada Centre for Remote Sensing of Energy, Mines and Resources Canada, the Public Land Division of Alberta Energy and Natural Resources, and the Alberta Remote Sensing Center of Alberta Environment undertook a joint project to determine to what extent present and future satellites could be used to determine the condition of rangeland in southern Alberta. The project was divided into a demonstration and a research and development component. The demonstration component was intended to show that current remote sensing technology can be used to determine range condition. The research and development component investigated to what extent the analysis could be quantified and whether future satellite sensors will provide more useful information to the range manager than the present Landsat multispectral scanner.

Eight test areas were chosen within the Mixed Grass Prairie and the Rough Fescue Prairie in southern Alberta. Three of these were intensive study areas where extensive ground and remotely sensed data were collected. These data included: (1) ground spectral reflectances collected with the CCRS Spectroscopy Laboratory; (2) scanner and colour infrared photography; (3) Landsat multispectral scanner (MSS) imagery collected to verify the findings from the intensive study area data.

From the initial qualitative analysis an enhanced Landsat colour composite image product was developed, which can be used to reliably determine range condition throughout the semiarid Mixed Grass Prairie. This same product was found to be not as reliable within the Rough Fescue Prairie, as there were ambiguities between some very poor and excellent range condition areas. The analysis of the simulated Landsat-D thematic mapper data indicated that the spectral band centred at 1.65 micrometres may remove some of the ambiguities in the imagery of the Rough Rescue Prairie.

Subsequent quantitative analysis of the Spectroscopy Laboratory data showed that there was no strong quantitative relationship between vegetation biomass and spectral reflectances. This is due primarily to the heterogeneous nature of the rangeland. A specific amount of biomass can be configured in many different ways with different amounts of standing green and brown biomass, litter, and the subsequent different shadowing.

These enhanced Landsat colour composite images have proved to be very useful in rangeland management and are being used at present by Public Lands Division, Alberta Energy and Natural Resources in their Lethbridge and Medicine Hat offices and by the Prairie Farm Rehabilitation Administration in Saskatchewan.

Résumé

Le centre canadien de télédétection (C.C.T.) du ministère de l'Energie des Mines et des Ressources, la Publics Lands Division, Alberta Energy and Natural Ressources et l'Alberta Remote Sensing Center de l'Alberta Environment ont enterpris, en 1980, un projet conjoint. Celui-ci vise à évaluer le potentiel d'utilisation des satellites, présents et futurs, pour la détermination de l'état des pâturages dans le sud de l'Alberta.

La première partie du projet consistait en une démonstration tandis que la deuxième, en un programme de recherche et de développement. La démonstration faisait ressortir le fait que la détermination de l'état des pâturages pouvait s'effectuer par télédétection. Le programme de recherche et de développement cherchait à déterminer le niveau de quantification de l'analyse et si les capteurs des satellites futurs fourniraient plus d'information, utile aux gestionnaires des pâturages, que le présent balayeur multispectral à bord de LANDSAT.

Dans le sud de l'Alberta, huit parcelles expérimentales étaient délimitées dans les prairies à graminées mélangées et à fétuque scabre. Trois d'entre elles étaient destinées à des études intensives visant à recueillir les données au sol et par télédétection. Ces données se divisent en trois points: (1) données de réflectance spectrale au sol, recueillies à l'aide du laboratoire de spectroscopie du C.C.T.; (2) données acquises par balayeur et par photographie infrarouge couleur; (3) imagerie acquise par balayeur multispectral (MSS) de LANDSAT destinée à vérifier les conclusions tirées à partir des données récoltées lors des études intensives.

A partir de l'analyse qualitative, une composition colorée rehaussée (de LANDSAT) était développée. Son utilisation permet de déterminer l'état des pâturages de la partie semi-aride des prairies à graminées mélangées. Cependant, ce type d'image est moins efficace pour le cas des prairies à fétuque scabre à cause des ambiguités entre les états extrêmes (mauvais et excellent) des pâturages. L'analyse de la simulation des données du "Thematic Mapper" de LANDSAT-D a fourni des indices selon lesquels la bande spectrale centrée sur 1,65 micromètres peut dissiper des ambiguïtés de l'imagerie couvrant la prairie à fétuque scabre.

Par la suite, l'analyse quantitative des données, provenant du laboratoire de spectroscopie démontrait une faible relation entre la biomasse de la végétation et les réflectances spectrales. Ceci s'explique par le caractère hétérogène des pâturages. En effet, les proportions de biomasse verte et brune, et de litière, formant une quantité spécifique de biomasse, peuvent varier. De plus, différents ombrages peuvent affecter l'évaluation de la biomasse.

Ces compositions colorées rehaussées (de LANDSAT) se sont révélées d'un grand secours à la gestion des pâturages. Elles sont présentement utilisées par la Public Lands Division, Alberta Energy and Natural Resources à Lethbridge et à Medicine Hat et par la "Prairie Farm Rehabilitation Administration" en Saskatchewan.

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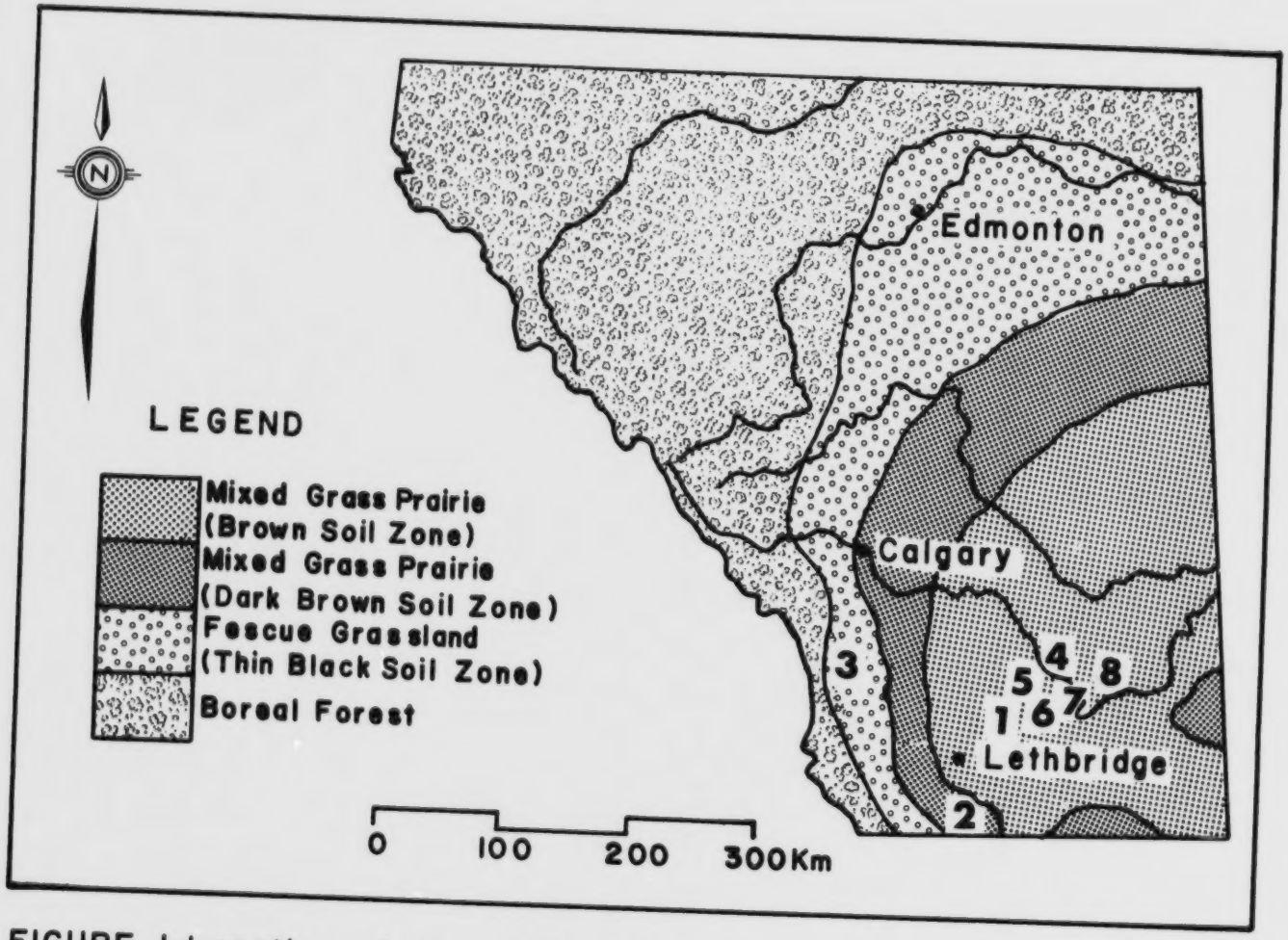

FIGURE-1: Location of the 1980 Study Areas in Southern Alberta

1. INTRODUCTION

1.1 BACKGROUND

In 1980 the Canada Centre for Remote Sensing of Energy, Mines and Resources Canada, the Public Lands Division of Alberta Energy and Natural Resources, and the Alberta Remote Sensing Center of Alberta Environment undertook a joint project to evaluate how effectively data from present and future satellites could be used to quantitatively evaluate range condition in an operational environment. In southern Alberta, public grazing lands comprise some 2.6 million hectares, which are administered through grazing leases or permits or developed into provincial grazing reserves, which are government-operated communal pastures. These public lands come under the jurisdiction of Public Lands Division, Alberta Energy and Natural Resources, who are responsible for regular inspection of the leased land and development of management plans. These inspections require time-consuming and expensive ground surveys.

With the launch in 1972 of the earth resources satellite Landsat-1, came the hope that the resulting data could be used to help evaluate range condition more rapidly and less expensively than traditional methods. Studies were conducted in 1975 (Intera, 1977) and continued in 1976 (Intera, 1979), to test this possibility. While not conclusive, these investigations did indicate potential usefulness for the data. Numerous other studies (Maxwell, 1976; Rouse et al., 1973; Deering et al., 1975; Deering and Haas, 1977; Harlan et al., 1979; Jaques and Cihlar, 1979; Thomson et al., 1980) show that there is no universal approach for range assessment using LANDSAT data. Common problems which hinder the reliable estimation of range condition and biomass quantities include a wide variety of species composition, different soil backgrounds, the differential growth rates of individual plants from site to site and the different spectral reflectance characteristics of green and brown biomass (Pearce, 1980). This study addresses these problems within two Canadian rangeland areas (Mixed Grass Prairie and Rough Fescue Prairie) with emphasis upon attributes of interest to range managers, such as biomass and range condition.

The project was divided into two segments: a demonstration component, which concentrated on what could be done with the present technology and knowledge, and a research component, which investigated (a) to what extent the analysis could be made quantitative and (b) whether future satellite sensors (such as the thematic mapper on Landsat-D) would be able to supply better information. Although the project was structured in this way, in practice there was not a distinct demarcation between the activities of the two components. For example, as will be explained in more detail in Section 3, the initial data products that were specified for the demonstration component were found to be inappropriate for use in western Canada and consequently research component resources were diverted to develop a better product. This illustrates the importance, at this point in the development of applications of remotely sensed data, of having research resources available for, and preferably an integral part of demonstration activities. Also, the approach used here involving an end user such as the range inspectors

of Public Lands Division, Alberta Energy and Natural Resources, is vital for developing successful applications of remotely sensed data. Without the feedback from these persons and their evaluation of the data products, it is unlikely that a product would have been developed which can be used to supply the required information needs.

It was agreed at the outset that all remote sensing products had to be practical. They had to provide coverage of large areas economically, be readily interpreted by field officers with only a minimal degree of training, and be readily reproduceable for continuity.

This project has lead to the specification of an image product that can be reliably used in the Mixed Grass Prairie region of western Canada to evaluate range "condition". Throughout this report, range condition is derived from a subjective judgement of the pasture condition rather than an objective evaluation of change in species composition of the range from the native state as defined by Smoliak et al. (1976a). From the Landsat imagery, it is not possible in most cases to carry out a detailed separation of grass species. However, it appears possible to get a good estimation of the amount of vegetation present.

This report gives a review of previous studies, the results of the demonstration and research work and a detailed description of the approach.

1.2 REVIEW OF PREVIOUS WORK

Radiant energy received at the earth's surface is absorbed or reflected within the internal cell structure of green living plants. Because of variations in plant size, leaf morphology, orientation, pigmentation, and internal physiology, individual plant species exhibit different absorption and reflectances (Carneggie et al., 1979; Gates, 1968; American Society of Photogrammetry, 1975; Totterdell and Rains, 1973).

As plants mature over the growing season, an increase in the size and amount of vegetation has been found to cause an associated change in reflectance in the near-infrared, which peaks at the height of maximum green foliage development. As the vegetation dries, reflectance in this wavelength decreases and, with the loss of chlorophylls associated with senescence, there is a reduction of radiant energy absorption in the visible region of the spectrum and a subsequent increase in reflectance (Carneggie et al., 1974).

Before considering the work that applies specifically to LANDSAT, it is useful to review some of the basic research on the spectral characteristics of grasslands. The most comprehensive ground-based spectrometer studies were carried out by Tucker (1977b, 1978a and b) in the Pawnee National Grasslands of Colorado on primarily blue grama (Bouteloua gracilis). The measurements spanned a range of grassland conditions with different percentages of green and senescent material.

Tucker (1977a) found high correlations between biomass, chlorophyll, leaf water content and the spectral reflectance measured in the 0.74 to 1.0 micrometre region in grasslands with greater than 80% green biomass content. Poor correlation between the above plant parameters and the reflectance was observed from 0.70 to 0.74 micrometre. For the situation with equal amounts of live and dead plant material (Tucker, 1977b) the reflectance measured at 0.63 to 0.69 and 0.74 to 0.80 micrometre showed the highest correlation with the live or green material. The dry brown biomass showed high correlations with the reflectance at 0.74 to 0.80 micrometre.

When the grass canopy was in the post-senescent phase, Tucker (1978a) found that the spectral reflectance tended to increase with increasing values of total wet and dry biomass. The increase was evident at all wavelengths from 0.68 to 0.80 micrometre. In his study, Tucker also found that the spectral region from 0.70 to 0.80 micrometre provided the highest correlations with the grass canopy variables of total wet and total dry biomass. However, the author did caution the extrapolation of his results because of the small sample size involved. Increases in reflectance at all wavelengths as a crop matures and the leaves senesce have been observed by Sinclair et al. (1971). In addition, there appeared to be an increased reflectance in the 1.30 to 2.26 micrometre region as the plant material senesced. Similarly, work by Olsen (1967) on a sycamore leaf with varying moisture content showed that as the leaf dried out, the reflectance increased in the 1.00 to 2.60 micrometre spectral region.

These measurements suggest that the preferred spectral region for the detection of green biomass lies in the photosynthetically active range of 0.63 to 0.69 micrometre. As the amount of brown or senescent material increases, separating the green and brown components becomes more difficult in the spectral range 0.74 to 1.1 micrometres. The apparent increase in the reflectance in the 1.3 to 2.6 micrometre region as the plant canopy senesces may be useful in the detection and measurement of the brown biomass.

The LANDSAT multispectral scanner (MSS) bands overlap some of the important spectral regions. For example, MSS 5 spans the green sensitive region from 0.6 to 0.7 micrometre whereas MSS 6 and MSS 7 cover the range 0.7 to 1.1 micrometres.

In recent years, there have been a number of investigations on the application of LANDSAT MSS data to rangeland vegetation monitoring. It must be emphasized that these studies cover a variety of different rangeland types. For example, the species composition and other conditions found in many of the American ranges are quite different from the native ranges found in southern Alberta. Thus, experiments should be compared cautiously.

Correlations between biomass and ratios of MSS bands and vegetation indices based on various permutations of the LANDSAT MSS band radiances have been observed by several workers (Maxwell, 1976; Rouse et al., 1973; Deering et al., 1975; Deering and Haas, 1977; Jaques and Cihlar, 1979; Thomson et al., 1980). One of the most

comprehensive studies was carried out by the Texas A & M group (Deering et al., 1975; Deering and Haas, 1977), who attempted to apply Landsat data to the estimation of green biomass under operational conditions over six states in the Great Plains Corridor. MSS data were used to derive green biomass values for 10 test sites. The biomass data were plotted on maps to show four categories of range forage condition varying from poor (250-750 kg/ha) to excellent (1500 kg/ha and greater). These range condition maps were found to compare favourably with the standard USDA Statistical Reporting Service Pasture and Range Feed Condition Maps over a 6.25 million hectare test area. However, site-related and other factors affected the accuracy of the green biomass estimation including the intrusion of common broom weed in September, meteorological effects, and flower and seed production in summer and early autumn. Of particular interest to our study is the underestimation of green biomass that resulted when standing brown biomass or carryover obscured new green growth. In addition, they found that there was a threshold value of about 250-500 kg/ha below which the biomass could not be determined.

Other studies have noted similar factors affecting the quantitative estimation of green biomass. The threshold problem has been observed in a number of experiments (Rouse et al., 1973; Harlan et al., 1979a; Pearce, 1980; Thomson et al., 1980) and appears to vary from 250 to 500 kg/ha depending on site-specific conditions. Several workers report that at the upper end of the green biomass scale, spectral reflectance tends to an asymptotic limit (Tucker, 1977b; Thomson et al., 1980), at which point reflectance increases very little with further increases in biomass. The asymptotic limit appears to fall in the range of 1000 to 2000 kg/ha.

From the studies in the U.S.A., it appears that there is no general agreement on the best time of year for green biomass estimations. Some workers report the best correlations in early spring and winter (Deering and Haas, 1977) but in other studies, the August period gave the best results (Harlan et al., 1979a and b).

Common problems that affect quantitative measurements include the inhomogeneity of rangeland vegetation and the differential growth rates of individual plants, which vary from site to site (Pearce, 1980).

Since most of the experiments in the U.S.A. relate to environments that are not typical of western Canadian rangeland, reviewing the pertinent Canadian experiments is important. Jaques and Cihlar (1979) demonstrated that correlation between LANDSAT radiance values and total biomass increased as the percentage of green biomass increased within a particular test location. Work in the parkland prairie of Saskatchewan by Thomson et al. (1980) showed correlations between LANDSAT data and green biomass in the July period and no correlations in the September period when there was a significant amount of brown biomass. However, good correlation between percentage of ground cover and LANDSAT data was observed in both July and September.

Studies in southeastern Alberta by Intera Environmental Consultants Ltd. (1979) showed that digital Landsat data could be classified only into general forage categories. In recent studies, Pearce (1980) derived a classification system for rangeland biomass in the Mixed Grass Prairie of southern Alberta based on Landsat digital data. In this study, low MSS digital values in bands 5 and 7 corresponded to higher grassland biomass when the range was composed predominantly of standing brown vegetation. Pearce was able to assign five biomass ranges to the test area. These ranges were very high (over 1000 kg/ha), high (800-999 kg/ha), medium (600-799 kg/ha), low (400-599 kg/ha) and very low (less than 399 kg/ha).

Rangeland studies which have emphasized the qualitative interpretation of Landsat data products have provided, in some cases, useful input to range managers. For example, Watson (1977) used LANDSAT imagery to map homogeneous vegetation units in rangeland near Kamloops, British Columbia. In another study, Carneggie et al. (1974) found that broad changes in rangeland could be monitored using Landsat images. Pearce (1980) also was able to relate tonal variations on Landsat images to general range condition.

A pilot project was initiated in 1976 in the Aspen Parkland at Rowley/Jakes Butte (130 km northeast of Calgary) by Public Lands Division, Alberta Energy and Natural Resources and Intera Environmental Consultants Ltd. (1977). In this project colour infrared aerial photography and Landsat imagery were used to evaluate the use of remote sensing to monitor rangelands. The results indicated that high and low grassland biomass could be separated visually on the LANDSAT imagery, but units with high biomass, could not, even if the differences were great. It was also noted that ranges with low green grass biomass but many broad-leafed flowering plants appeared red on the imagery. As part of the pilot project, similar research was carried out on Fescue Grasslands at the Agriculture Canada Research Station near Stavely, at the northern end of the Porcupine Hills. Again, the comparatively high biomass levels associated with these grasslands could not be differentiated.

Problems associated with the application of quantitative models preclude their immediate operational use. However, the consensus appears to be that LANDSAT data have a potential role to play in operational rangeland management.

2. DATA ACQUISITION

2.1 THE STUDY AREAS

2.1.1 General Description

Southern Alberta is characterized by native grasslands with a cover of short to medium grasses and low forbs and shrubs. With the exception of the foothills and mountains in the western part of the province, trees are generally restricted to river valleys and isolated plateau uplands, or have been planted as shelterbelts around farms and ranches. Although large areas of grassland range still remain for grazing, much has been ploughed and replanted to introduced forage species or cash crops. The native grasslands may be roughly divided into two main regions - the Mixed Grass Prairie and the Fescue Grasslands. Figure 1 shows the extent of these regions in Alberta. The present study was carried out in the Mixed Grass Prairie in central and eastern Alberta and the Fescue Grasslands in the south and southwestern parts of the province. These areas will be described in detail in the following sections.

2.1.2 The Mixed Grass Prairie

The Mixed Grass Prairie in Alberta extends from the Alberta-Saskatchewan border west to the Foothills of the Rocky Mountains, south to the International Boundary, and north to the Aspen Parkland zone. The Mixed Grass Prairie is associated with the Brown and Dark Brown Soil zones of Alberta, which have developed under semiarid conditions of low precipitation (from 250 to 350 mm) and high evaporation. Brown soils have shallow profiles, are generally low in organic matter, nitrogen and phosphorous, and have a compact calcium carbonate layer close to the surface (Canadian Soil Survey Committee, 1978; Smoliak et al., 1976). The soils in most of the Mixed Grass Prairie have developed from glacial tills composed of locally derived materials deposited by continental glaciers or from underlying marine shales and sandstones where the drift deposits were thin. Chernozems are the dominant soils in the Mixed Grass Prairie but solonetzic soils are also commonly associated with this grassland. Specifically, these soils are characterized by a higher sodium content, poorer structure, and an impervious B horizon, which forms a hardpan layer close to the surface. The upper soils may become powdery with drying and are very susceptible to erosion or "blowout", giving a pitted appearance to the landscape (Bunting, 1965).

Needle-and-thread (Stipa comata) dominates the region on medium- to coarse-textured soils in combination with northern wheatgrass (Agropyron dasystachyum), blue grama grass, and June grass (Koeleria cristata). Fringed sage (Artemisia frigida), sagebrush (A. cana), moss phlox (Phlox hoodii), and thread-leafed sedge (Carex filifolia) are important forbs and shrubs. Little club moss (Selaginella densa) and pussytoes (Antennaria spp.) can cover large areas of the ground surface, particularly on shallow soils where blue grama grass and sedge are more prevalent (Pearce, 1980).

On lacustrine clays, western wheatgrass (A. smithii) becomes dominant in association with June grass. Western wheatgrass is also dominant on solonetzic soils with June grass and blue grama grass. Prickly pear cactus (Opuntia polycantha) and pincushion cactus (Mamallaria vivipara), sagebrush, and saltsage atriplex (Atriplex nuttallii) are also common in these areas.

Depressional areas with above-normal moisture support denser vegetation comprised of western wheatgrass, tufted hairgrass (Deschampsia caespitosa), Nuttall's alkali grass (Puccinellia nuttallina), foxtail barley (Hordeum jubatum), yarrow (Achillea lanulosa), and owl clover (Orthocarpus lutens). Sandgrass (Calamovilfa longifolia), Indian rice grass (Oryzopsis hymenoides), rose (Rosa arkansana), and golden bean (Thermopsis rhombifolia) are characteristic species of stable dunes in the area. Chokecherry (Prunus virginiana), saskatoon-berry (Amelanchier alnifolia), and other taller shrubs are found on protected slopes and moist coulee bottoms, while willow (Salix spp.), western cottonwood (Populus deltoides), and narrow-leafed cottonwood (P. angustifolia) are dominant along rivers.

Vegetation growth in the Mixed Grass Prairie begins relatively early in the spring, as early as the end of March in some years. The grasses have adapted to the summer droughts associated with the Brown Soil Zone by senescing early. Thus, by the end of July, most of the vegetation may be dried.

Differences in topography and soils and fluctuations in annual and seasonal precipitation contribute to significant variations in vegetation biomass over range areas in the Mixed Grass Prairie. Total biomass associated with good range condition varies from 300 to over 1000 kg/ha, depending on the productivity of the site (Pearce, 1980). The vegetation usually covers less than 50% of the ground surface except for little club moss and pussytoes. Stocking rates are low - from 2.0 to 4.0 ha/animal-unit month (Johnston et al., 1967). Heavy grazing reduces the forage yield of the vegetation by eliminating the more desirable mid-grasses such as needle-and-thread, northern wheatgrass, and western wheatgrass, so that blue grama grass, Sandberg's bluegrass (Poa secunda), and weedy species become prevalent (Smoliak et al., 1976a). Prolonged drought also affects yield by reducing the vigour of the vegetation, inducing dormancy, changing species composition, and finally lowering plant density (Coupland, 1958).

2.1.3 Fescue Grasslands

The Fescue Grasslands in Alberta, which comprise the Parkland north and east of Calgary, the Cypress Hills Plateau, and the Foothills paralleling the Rocky Mountains in the west, are areas of greater moisture availability than the Mixed Grass Prairie. This grassland type is associated with the Black Soil Zone where rough fescue (Festuca scabrella) is the dominant species under relatively undisturbed conditions. Fescue is also found in some parts of the Dark Brown Soil Zone where it is mixed with species of the Stipa association. The fescue association is more luxuriant and

species-rich than the Mixed Grass Prairie. Forbs and low shrubs form an important part of the plant canopy, and the grasslands are often interspersed with stands of aspen and willow, and even lodgepole pine (Pinus contorta), white spruce (Picea glauca), and Douglas fir (Pseudotsuga meniesii) in the higher foothills. The well-drained black chernozems associated with the Fescue Grasslands have formed on loamy, moderately calcareous glacial till (Wyatt and Newton, 1925). The gentle to rolling topography ranges in elevation from 1250 to 1520 m asl. Most of the Fescue Grasslands have now been cultivated except where rolling terrain impedes farming and ranching predominates.

The dominant species in the Fescue Grasslands is rough fescue. When undisturbed, large tussocks (25 to 50 cm in diameter and 30 to 90 cm high) characteristic of this species and the dense buildup of unincorporated leaf litter can exclude other plants completely or restrict their growth to areas between the tussocks (Moss and Campbell, 1947). Associated grasses in the Fescue Grasslands include Parry's oatgrass (Danthonia parryi), which can be locally dominant on the shallow soils of gravel and rocky sites, Columbia needlegrass (Stipa columbiana), bearded wheatgrass (Agropyron subsecundum), and Richardson needlegrass (S. Richardsonii) (Coupland, 1961; Moss and Campbell, 1947; Smoliak et al., 1976; Johnston et al., 1967). Lupine (Lupinus sericeus), sticky wild geranium (Geranium viscosissimum), hoary puccoon (Lithospermum ruderale), northern bedstraw (Galium boreale), and aster (Aster spp.) are common forbs. Shrubs such as western snowberry (Symphoricarpos occidentalis), rose and shrubby cinquefoil (Potentilla fruticosa) are also important. Large stands of aspen poplar (Populus tremuloides) and willow are associated with the grasslands in the higher foothills. Some areas have been planted to introduced forage types such as bromegrass (Bromus inermis) and timothy (Phleum pratense).

Vegetation growth in the Fescue Grasslands begins somewhat later than in the Mixed Grass Prairie, usually about the first part of June. However, the early senescence associated with the summer drought in the Brown Soil Zone does not normally occur in the Fescue Grasslands.

The comparatively luxuriant growth, characteristic of the Fescue Grasslands, results in almost 100% coverage of the soil surface. Forage yields of range in good condition average 2000 to 4000 kg/ha. The stocking rate is higher than that of the Mixed Grass Prairie and varies from 1.5 to 3.5 ha/AUM, depending on the condition of the range (Johnston et al., 1967).

Rough fescue is sensitive to summer grazing (Johnston et al., 1967). With continued heavy use, the tussocks are reduced in size and the species is eventually replaced by Parry's oatgrass, Idaho fescue (Festuca Idahoensis), June grass, and the bluegrasses, and forbs and shrubs become more prevalent. Prolonged heavy utilization results in a cover of weedy species such as fringed sage, foxtail barley, and dandelion (Taraxacum officinale).

2.2 INTENSIVE STUDY AREAS

Three areas were selected for intensive study - Little Bow/Travers reservoirs (1)* in the Mixed Grass Prairie vegetation zone northeast of Lethbridge, Ross Lake (2) in the Mixed Grass Prairie/Fescue Grassland transition zone on the Milk River Ridge southwest of Lethbridge, and the Agriculture Canada Range Research Station (3) in the Fescue Grasslands west of Stavely. As well, grazing leases in the Mixed Grass Prairie were used to evaluate the Landsat imagery in the field. These areas were Scandia (4), East Lomond (5), Vauxhall (6), and Hays(7).

2.2.1 Little Bow/Travers Reservoirs

The Little Bow and Travers reservoirs (1) are located near Lake McGregor, 80 km northeast of Lethbridge, within the Brown Soil Zone. The area includes a large grazing lease around Little Bow Reservoir, a provincial grazing lease adjacent to Travers Reservoir, and numerous deeded rangelands north and east of the reservoirs.

The climate of the high plains in southern Alberta is characterized by long cold winters moderated by warm "chinook" winds (which melt the snow and dry out the soils), hot summers, and low precipitation rates. Soils in this area are predominantly well-drained Orthic Brown Chernozems formed on moderately calcareous glacial till. Small areas of solonetzic soils occur west of Little Bow Reservoir, and stable sand dunes are common along the southeast shore of this reservoir. In some areas, considerable depths of gravel underlie the topsoil. The topography is generally undulating to gently rolling. Steep-sided slopes form the valley of the Little Bow River and eroded cliffs ring Travers Reservoir and McGregor Lake.

Although the vegetation is generally representative of the Mixed Grass Prairie, the proximity of the area to the Dark Brown Soil Zone is reflected by the presence of species usually characteristic of moister areas, such as porcupine grass (Stipa spartea) and western snowberry. The biomass is generally higher even in quite heavily grazed ranges. Needle-and-thread, western and northern wheatgrass, blue grama grass, and June grass are the dominant grasses on medium-textured soils where grazing is light to moderate. The wheatgrasses, blue grama grass, and two species of cactus, prickly pear and pincushion, are more prevalent on the saline soils. Sandgrass, golden bean, and rose are found on stable sand dunes. Porcupine grass is mixed with the other grasses on cool, moist north-facing slopes while western snowberry, rose, and wild licorice (Glycyrrhiza lepidota) are found in protected lows. On the thin soils of knolls and in areas of heavier cattle use, needle-and-thread and the wheatgrasses are less important compared with blue grama grass, bluegrass, sedge, and fringed sage.

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*Numbers in parentheses refer to location on Figure 1.

2.2.2 Other Areas in the Mixed Grass Prairie

The Scandia, East Lomond, Vauxhall, Hays, and Bow Island grazing leases were not studied in the same detail as Little Bow/Travers but were used primarily to evaluate the LANDSAT imagery products.

The Scandia Grazing Association (4) on the east bank of the Bow River near the town of Scandia and the East Lomond lease (5) just west of the river are quite similar topographically to Little Bow/Travers. There are large areas of stable sand dunes and undulating to gently rolling terrain underlain in places by thick deposits of alluvial gravels. The vegetation, too, is generally similar, although western snowberry is not present. Large areas are covered by sagebrush, particularly where grazing is heavy and on alluvial flats beside the river.

At Scandia, trees planted around abandoned homesites and a former federal government sheep research station are present. Willows and other tall shrubs are found on low banks adjacent to the Bow River and around a large slough which dissects the area in the north. As well, some of the lease has been reseeded to crested wheatgrass. The northern part of the lease appears to have been grazed quite heavily in the past so that grass cover is sparse and sagebrush and fringed sage are very prevalent. The East Lomond lease is divided into several very large pastures in which the western portions are generally underutilized as cattle concentrate in the eastern sections. Solonetzic soils with prominent blowouts and saline depressions are found in the northern part of the lease. This area is heavily used when cattle are put onto the lease in spring.

The Vauxhall and Hays grazing leases (6 and 7 respectively) are located farther south and are characteristic of the grasslands of the more arid parts of the Brown Soil Zone. The Vauxhall Grazing Association has one of the largest leases evaluated in the study (approximately 33 000 hectares). The terrain is level to gently undulating and the soils are very sandy with the exception of large areas of heavy saline soils in the western part of the lease. Small depresssions that dry up by early summer are found throughout the lease and a large slough dammed at one end is located at the eastern boundary of the lease. Much of the lease appears to have been rather heavily utilized in the past and large areas of range in poorer condition are evident. Sagebrush and fringed sage are common, and form dense patches in some of the pastures.

The Hays Grazing Association lease (approximately 23 000 hectares) east of the Vauxhall lease extends to the Bow River. A large band of stable sand dunes in the northern part of the lease has formed choppy sandhills. The rest of the lease is level to gently undulating. Here, as well, much of the lease appears to have been heavily utilized in the past, and the amount of the more palatable grasses has been reduced and replaced by blue grama grass, bluegrass, cactus, fringed sage, and sagebrush. Disturbances associated with several gas production facilities, access roads, and a series of irrigation canals, have led to the invasion of weedy annuals in some areas.

2.2.3 Ross Lake

This area is located approximately 40 km south of Magrath on the southern slopes of the Milk River Ridge (Figure 1). The general physiography is a rolling morainic till plain and eroded plateau with many steep-sided coulees dissecting the upland areas. The topographic variability and increased elevation (1070 to 1370 m asl) associated with the ridge results in slightly cooler temperatures and increased precipitation compared with the adjacent plains.

Ross Lake lies within the Dark Brown Soil Zone, which in this area is more a transition zone between the Brown Soils to the south and east and the Shallow Black Soils to the northwest. The soils have formed on moderately calcareous tills with inclusions of gravel and tertiary bedrock (Canadian Soil Survey Committee, 1978). Textures vary from heavy loams to clay loams. The soils are very productive and suitable for agriculture, but the rough topography associated with the Milk River Ridge precludes extensive farming in this area and ranching is predominant.

The dominant vegetation type is characteristic of the Fescue Grasslands. However, because this area is within the Dark Brown Soil Zone, and near the Brown Soil Zone, species more characteristic of the Stipa association of the semiarid plains are also found. This is particularly so on the drier knolls, ridges and south-facing slopes, and where there has been a decrease in rough fescue and the protective litter buildup has been removed.

Rough fescue is dominant on light to moderately grazed ranges. On the uplands, the fescue is seldom grazed by cattle and the tussocks can be very large with a very thick buildup of litter (as much as 40 to 50 cm deep). In these areas, rough fescue stands appear almost monospecific, with scattered plants of Idaho fescue, lupine, sticky wild geranium, rose, and western snowberry exhibiting feeble growth between the tussocks. Cattle tend to concentrate on the lower pastures in the many coulees that dissect the uplands, and around dams and salt licks. In these areas, rough fescue has been replaced by grasses more representative of the Brown Soil Zone, such as needle-and-thread, blue grama grass, June grass, and bluegrass as well as Idaho fescue, several species of wheatgrass, western snowberry, rose, and a more luxuriant growth of such forbs as geranium and lupine.

2.2.4 Stavely

The Agriculture Canada Range Research Station approximately 20 km west of the town of Stavely (3) in the northern Porcupine Hills was the site of detailed investigations in the Black Soil Zone. Although the evaluations were concentrated on the research station itself, some reconnaissance was carried out on adjacent leases and deeded pastures operated by private ranches.

The Stavely Research Station is situated in an area of rolling to hilly topography where elevations vary from 1250 to 1520 m asl. The climate is characterized by long, cold winters and relatively cool summers. However, temperatures can fluctuate widely because of the moderating effect of warm, dry chinook winds. Average yearly precipitation is 50 cm, much of which occurs as rain in the spring, although snowfall in the foothills can be quite heavy and contribute greatly to the soil moisture regime. Soils are generally silty loam in texture. Lenses of gravel underlie some areas and bedrock outcrops, primarily sandstones, are common. The increased precipitation results in tall shrubs and trees, primarily willow and aspen, within the Fescue Grasslands in the immediate study area whereas white spruce, lodgepole pine, and Douglas fir are prevalent farther west. Ranching is predominant in the area although farming is carried out at lower altitudes.

As this study area is located on a government research facility, the grazing patterns are not typical of the surrounding areas. Four of the pastures have been under a controlled grazing regime since the early 1940s and represent conditions resulting from very heavy, heavy, moderate, and light cattle utilization. The remaining pastures on the station are now used only as temporary holding fields and bromegrass and timothy have volunteered over large areas.

The vegetation on the research station reflects the various grazing pressures. Under light grazing, rough fescue is dominant on the uplands. Here it is in excellent condition with large tussocks and a thick buildup of litter. Parry's oatgrass, bearded wheatgrass, wild geranium, lupine, anemone (Anemone patens), snowberry, and rose are interspersed among and within the fescue tussocks. Parry's oatgrass is dominant on south- and west-facing slopes of the reserve pastures, particularly on light-textured shallow soils and with increasing grazing pressure (Johnston and Dormaar, 1970). As at Ross Lake, cattle concentrate in the lower areas in coulees and around dams. In these areas, the fescue has been replaced by bluegrass, several species of wheatgrass, needle grass, and low-growing forbs and shrubs. Under moderate grazing, rough fescue is still present especially on the less accessible uplands and steep slopes. However, the tussocks are significantly smaller with less buildup of old clumps and leaves, and Parry's oatgrass and the associated forbs and shrubs, particularly shrubby cinquefoil, are much more prevalent. Rough fescue is largely replaced by Parry's oatgrass, Idaho fescue, and bluegrass, and the coverage of forbs and shrubs is much increased under heavy grazing. Under the heaviest cattle use, the vegetation appears much more like that present in the Dark Brown and Brown Soil zones, with a sparse coverage of very short grasses and low forbs and shrubs. Parry's oatgrass under this regime has adopted a decumbent growth form. As well, the underlying soils appear to have been transformed to soils more characteristic of a drier microclimate; i.e., Dark Brown Chernozems, with a reduction in organic matter in the upper soil horizons (Dormaar et al., 1977). Increaser and invader species such as shrubby cinquefoil, snowberry, rose, dandelion, and fringed sage have become persistent, and the carryover and litter buildup are much reduced.

2.2.5 Areas Near Stavely

Pastures adjacent to the Stavely Research Station were also used to evaluate the satellite imagery. To the south, downvalley from the station, large range areas operated by local ranchers are similar to the moderately to lightly grazed pastures on the research facility. In these there are rough fescue communities in good condition on the uplands, and Parry's oatgrass dominant on upper south-facing slopes. Lower valleys and coulee bottoms receive heavy grazing pressure and species composition is primarily wheatgrass, needle grass, timothy, and various forbs and shrubs. Pastures on uplands above the research station in the eastern part of the area are dominated by Parry's oatgrass and upper coulee slopes are covered by a dense shrub growth of saskatoon, chokecherry, snowberry, and rose. Adjacent ranges to the north are dominated by shrubby cinquefoil, Parry's oatgrass, and bluegrass on upper slopes interspersed with aspen and willow groves. Low shrubs such as gooseberry (Ribes oxyacanthoides), saskatoon, and rose occupy the moist coulee bottoms. Grazing is quite heavy in these pastures, even on the uplands, and few stands of rough fescue remain.

2.3 SPECTRAL DATA

For this study, ground spectral data, Landsat MSS imagery, and airborne MSS and colour infrared (CIR) photographic data were collected. The ground spectral data were collected using a spectroradiometer (Brown and Ahern, 1980) which was sensitive to electromagnetic radiation in the region from 0.4 to 14.0 micrometres. This data set was collected to ascertain whether there is a direct relationship between any of the parameters relevant in rangeland management and the reflectances from the terrain. Spectral reflectances in 5 one-half metre square plots were determined at approximately ten sites at each of Little Bow, Ross Lake and Stavely. At each of these measurement locations, three of the five plots were clipped to determine the amount of biomass present. The details of the clipping procedures, the actual measurement sites and the results of the analysis of the spectral data are given in Section 4.

Airborne MSS data were collected to extend the interpretation of the data taken with the ground laboratory over a larger area. The CIR photos were acquired (at the same time as the airborne MSS data) to help document the area. The airborne MSS data were collected from a Falcon Fan Jet aircraft using a modified Daedalus model 1260 multispectral line scanner. This is a dual channel device which, within one channel, collects data in 10 spectral bands from 0.4 to 1.1 micrometres and in the other can collect data within the spectral region from 1.1 to 2.4 micrometres. For this study, we used this channel to collect reflected energy in a band from 1.55 to 1.75 micrometres, which corresponds to band 5 of the thematic mapper to be carried on Landsat-D. Of the ten bands between 0.4 and 1.1 micrometres, four are very similar to the first four thematic mapper bands and were selected for the thematic mapper performance study.

Landsat MSS imagery was collected for two reasons: to demonstrate what the technology was capable of currently and to extrapolate the conclusions from the analysis of the airborne and ground measurements to a larger area.

As noted above, clipping was carried out at the three intensively studied areas, Ross Lake, Stavely and Little Bow. The vegetative matter was separated into grasses, forbs and shrubs and standing green, brown and litter. These clippings were weighed in the field immediately after clipping, dried at the Agriculture Canada Lethbridge Research Station and weighed again. Besides the clippings that were collected to correlate with the ground spectral measurements, clippings were made along several transects at each of these sites. These data were used to quantitatively evaluate the Landsat MSS data. This will be discussed in more detail in Section 4.

3. DEMONSTRATION COMPONENT

3.1 INTRODUCTION

The objective of the demonstration component was to assess and demonstrate the capability of present satellite imagery to aid rangeland managers in carrying out their operational mandate. A subsidiary objective was to specify a data product that could be reliably used by these rangeland managers in southern Alberta.

Based upon a review of past work and our experience in the parkland range areas of Saskatchewan (Thomson et al., 1980), we decided that a qualitative interpretation of Landsat image products was most suitable for the demonstration component. This decision was made since past work on the quantitative determination of biomass using various Landsat vegetation indices showed that the estimation of green biomass becomes unreliable as the proportion of carryover or brown biomass increases. In addition, the best season for the estimation of green biomass seemed to vary according to conditions specific to individual sites. The quantitative determination of rangeland biomass was investigated as part of the research component of this work and is presented in Section 4 of this report.

From the start of the project, we planned to work directly with the rangeland managers. In general, they have a limited knowledge of satellite data but usually are familiar with the interpretation of black and white aerial photography. This was another reason for emphasizing the qualitative interpretation of range condition using Landsat image products rather than the more complex assessment of biomass using various band combinations.

During the 1980 grazing season, we made four trips, of approximately two weeks per visit, to several large rangeland areas near Lethbridge, Alberta. These field visits occurred during June, July, August, and September. During the period June to August, only those areas that came under the jurisdiction of the Lethbridge Office of Public Land Division were visited. In September, areas near Lethbridge and three large leases in the Medicine Hat area were visited. On each field visit, the CCRS staff were accompanied by the manager responsible for the particular lease. The Landsat image for the site was interpreted in cooperation with the rangeland managers. The trips were planned so that the scientist travelling from Ottawa would bring out the most recent Landsat image. Originally we estimated that we would produce image products within 10 to 14 days from the date of an overpass. In practice, this was difficult to achieve, although on two occasions we did go into the field with data less than two weeks old.

For the initial field trip in early June, a 1:250 000 Cibachrome enlargement of the Lethbridge area as well as several regular black and white and colour images of the same Landsat scene were used. On evaluation, it was found that contrasts on these images that related to range condition were difficult to see and interpret. In addition, the scale of the imagery, 1:250 000 for the Cibachrome enlargement and 1:1 000 000 for the normal Landsat products, was too small for observing the sort of detail which was of interest to the range

managers. The Cibachrome products were also too large for easy use in the field and tended to crack quite easily.

These limitations of the data were taken into account and for the second trip Polaroid prints were taken directly from the television monitor of the CCRS Image Analysis System (CIAS) (Goodenough, 1979). These images had been digitally stretched to enhance the contrasts in the rangeland areas and were approximately 1:150 000 in scale. This set of data products was found to contain significant information of interest to the range managers. They were able to locate and differentiate good and poor range conditions in the Mixed Grass Prairie leases. On the third and fourth trips, the data product was modified in accordance with requests from the range managers. For example, the images were geometrically corrected so that north appeared at the top of the image. In addition, the photographs of the CIAS scene were enlarged to produce a 20 X 25 cm colour image of the area at a scale of approximately 1:50 000. An attempt was also made to standardize the enhancement. A detailed description of the procedure to produce these digitally contrast stretched (DCS) images is given in the next section.

3.2 DIGITALLY CONTRAST STRETCHED DATA

Tonal variations within the rangeland areas were discernible on the colour composite Landsat MSS images. These images were made by modulating the intensities of the blue, green and red guns of the display monitor with the intensities of the Landsat MSS bands 4, 5, and 7, respectively. However, these variations were quite subtle. Consequently, we decided to do a linear contrast stretch of the image to highlight these variations. However, simply carrying out a contrast stretch without concern for sun angle and atmospheric effects would result in no consistency from image to image. To overcome this, an atmospheric correction was made on the data using the clear lakes method (Ahern et al., 1979), which includes a correction for sun angle, and then the Landsat radiance values were converted to reflectances. A linear stretch was then performed on the data so that specified minimum and maximum reflectances for the three bands corresponded to digital counts of 0 and 255 respectively. These minimum and maximum values were 2 and 24% for MSS bands 4 and 5, 12 and 30% for MSS band 7 in the June to August period and 8 to 28% for MSS band 7 in September and October. It was found that the change in band 7 limits in September and October helped distinguish the various range condition classes once senescence had decreased the amount of green vegetation present. The next problem was to move this enhanced image from computer memory to a product that could be used in the field. We decided to display the image on the CIAS screen, photograph the screen and then produce enlargements from the resulting negatives.

Early in demonstration component, the digitally contrast stretched imagery products were found to be a good indicator of range condition within the Mixed Grass Prairie. However, the interpretation of similar imagery of the Fescue Prairie was more difficult. Consequently, our efforts in the demonstration component of this project were directed towards the Mixed Grass Prairie while research and development continued on the Fescue Prairie. The results of this research on the Fescue Prairie is presented in

Section 4. It may be that part of the confusion within the Fescue Prairie is related to the effects of varying slope and aspect of the terrain. Slope and aspect corrections were not carried out in this study but will be done shortly using a digital terrain model.

3.3 EXAMPLES

This section will present a comparison between the Landsat imagery and three major variables: vegetation, site, and the effects of man's activities. These variables are easily identified and measured in the field, are being used in range evaluations and inventories and, consequently, are pertinent to an evaluation of the images for application to rangeland management.

Vegetation is probably the most obvious feature detected by satellite sensors. Vegetation type and composition, ground cover and biomass, and seasonal changes were variables which were considered when analyzing the imagery. The type and density of the vegetation is a function not only of grazing intensity but also site. Each distinct kind of rangeland constitutes a range site that has its own environment and a certain potential for producing distinctive range communities. Different range sites can be recognized through variations in the types or amounts of plants that make up the original plant community. These variations of a plant community may result from differences in depth, texture, and salinity of the soil, from differences in topography, climate, and exposure, and from differences in the level of the water table. Table 1 lists the more common range sites present in Alberta.

3.3.1 Little Bow and Travers Reservoirs

The area around the Little Bow and Travers reservoirs was chosen as one of our three major test areas where satellite, airborne, ground spectral and ground biomass clipping data were collected and analyzed.

A July 8, 1980 DCS image of this area is shown in Figure 2(a). Throughout the rangeland area there is a variation in the tones on the DCS images from dark blue to light bluish grey and even to a light red. We found that ranges in good condition dominated by native grasses such as needle-and-thread and the wheatgrasses appear medium to dark blue on the imagery. Pastures planted to crested wheatgrass appeared the darkest. Ranges in fair condition, with much of the vegetation removed by grazing, are lighter in tone as are poor quality sites with sparse vegetation cover such as on the steep slopes of the river valley or the tops of knolls. Ranges in poor condition appear light pink or mottled pink/blue if forbs, shrubs, or short green grass are present or a very light blue if the vegetation has senesced. Figures 2(c) to 2(g) show examples of the above effects. Figures 2(c) and 2(d) are ground photos taken from position A (Figure 2(b)) facing north and south respectively. The area to the north is in excellent condition whereas that to the south is only fair. A change in brightness on the Landsat image corresponds to this change in condition. Figure 2(e) is taken from position B facing north. In this area, there is very little carryover and a high proportion of forbs. Hence the dark blue tones on the Landsat

image of the excellent range contrast vividly with the lighter tones and mottled red appearance (caused by increased amounts of forbs) of the poorer range.

Another feature that stands out very distinctly on the Landsat imagery is at area C (Figure 2(b)). The dark blue field is a planted crested wheatgrass field while the surrounding area is range in fair condition. The cattle graze on crested wheatgrass only early in the growing season and later in the season prefer the surrounding needle-and-thread. Figures 2(f) and 2(g) show the crested wheatgrass field and the surrounding area to the east, respectively. This area to the east has a great deal of fringed sage and very little carryover.

This analysis can be made less subjective by considering the vegetation data that were collected. Table 2 gives the average weights of grasses, forbs, shrubs and litter along seven transects located throughout this area (see Figure 2(b)). A definite qualitative relationship can be seen between the amount of litter (which includes standing brown biomass) and the image tones. For example, consider transects 1, 5 and 7, which traverse respectively poor, excellent and fair rangeland. The vegetation along these transects is dominated by needle-and-thread and blue grama. Transects 1 and 7 have approximately 6 to 10% of the brown matter that is present along transect 5. The Landsat image is a dark blue at the location of transect 5 but is lighter and contains more red at the locations of transects 1 and 7.

The clipping data (Table 2) show that the area along transect 1 had the lowest biomass of the sampled areas, not only in July but also during the other sampling periods (794 kg/ha in June, 592 kg/ha in July, 485 kg/ha in August, 760 kg/ha in September, and 486 kg/ha in October). As well, there was significantly less carryover and surface litter present (only 17% of total in July when other transects had 34 to 53%). The grasses were short and covered much of the ground as is illustrated in Figure 2(e). With the absence of the brown carryover and litter, the green grass reflects relatively strongly in the near infrared and absorbs in the red and so appears pinkish on the DCS imagery. Here the pink tones do not represent a luxuriant stand of vegetation.

The lightness of the overall tone on the imagery of the area results from reflectance from the underlying light-coloured sandy soils and little club moss exposed between the plants and the lack of shadows usually present in a more vigorous grass canopy.

Transect 7 is also located in an area of range in poor condition. On the image, this area is mottled pink/light blue and is slightly darker in tone. The gently undulating topography of the ranges in the Little Bow area imparts a mottled appearance to the imagery with alternating patterns of sparse and thick vegetation growth associated with poor-quality sites on knolls and productive low areas.

Transect 5 traverses the area of highest biomass (both green and brown). On the imagery (Figure 2(a)), this area appears a dark blue.

This area is seldom grazed by cattle as it is separated from the rest of the lease by the dam on Little Bow Reservoir, an irrigation canal, and a major road. Also within this area are large expanses of stable dunes with an extensive cover of sandgrass. This grass, although very vigorous, is not particularly palatable to cattle after the early spring growth and so is not often heavily grazed, resulting in heavy carryover.

A change in tone in the area of transects 1 and 7 was noted from June and early July to the end of July. In early July, this area had a more pronounced pink tone, which had faded by the July 26, 1980 overpass (Figure 2(h)). This was caused by a decrease in the amount of chlorophyll absorption as the vegetation became drier rather than by a change in the mix of vegetation types.

The rangeland represented by transects 1 and 7 was grazed early in the spring in 1980 and the cattle moved to pastures west and north by early summer. Thus, these ranges were rested and the vegetation allowed to recover somewhat throughout the rest of the growing season. Hence the higher biomass on these transects in August and September.

This suggests that the amount of brown matter has a substantial effect upon the surface reflectance. As the amount of brown matter decreases, the green matter becomes predominant, which results in an increased MSS band 7 reflectance and hence increased red tones on the imagery. The combined effect of brown material and the shadows caused by the higher standing grasses probably causes this reduced band reflectance. A similar result (decreased MSS band 7 reflectance with increased standing brown biomass) has been found during a previous study on the Agriculture Canada One Four Research Station in southern Alberta (Pearce, 1980). This is one of the reasons why biomass indices calculated from MSS bands 5 and 7 reflectances are not good indicators of range condition in the Mixed Grass Prairie of western Canada. Band 7 reflectance values increase with increasing amounts of green biomass but decrease with increasing amounts of brown biomass. Hence, depending upon the area, time of year, and meteorological conditions, the same vegetation index value could mean a completely different range condition.

Transect 4 (Figure 2(b)) is located just west of Little Bow Reservoir in an area that is separated from the ranges to the north, south, and east by two irrigation canals connecting the Travers and Little Bow reservoirs. On the July imagery, this area is light to medium blue with a mottled appearance due to the uneven topography. There is a large area of crested wheatgrass planted just west of the transect with biomass ranging from 1240 to 2080 kg/ha, which may attract cattle in the spring when growth of the native species is not as vigorous. As well, there are some areas of solonetzic soils here that may reduce productivity where the topsoils have been eroded. The ranges are predominantly in fair condition, especially close to both reservoirs. This is evident from the clipping data since the relatively high total biomass recorded in July and August (1848 kg/ha and 924 kg/ha, respectively) had a high component of unpalatable broad-leafed plants (28% and 47% of total biomass in July and August) mixed in with the grasses. Also, species composition appeared to

have shifted somewhat to wheatgrasses and bluegrasses, which also may have increased the clipped weights. This transect shows more carryover and litter in June and July (36% and 34%) than later (only 17% by August) as a result of increased use in summer when cattle were moved to this area from ranges to the south and east. However, this pattern was difficult to discern on the imagery as on overpasses in June and early July this area had been dominated by pink tones, which have almost disappeared by the July 26, 1980 overpass (Figure 2(h)).

Transects 0 and 5 illustrate the darker appearance of crested wheatgrass. Along transect 5, the tone on the Landsat image is not as dark as that along transect 0, for two reasons: (1) along transect 5 there is substantially more standing green biomass (1885 kg/ha compared with 853 kg/ha along transect 0) which would increase the MSS band 7 reflectance and hence increase the brightness of the image, and (2) the area along transect 0 is covered with crested wheatgrass and that along transect 5 with sandgrass. These two grasses have a different spectral signature. From the ground spectral studies, it was found that the crested wheatgrass had a substantially lower Landsat MSS band 7 reflectance than needle-and-thread and sandgrass. A good example of this is seen at location D (Figure 2(b)) on the Landsat image where a transition from crested wheatgrass to native grasses is clearly discernible. Figure 2(i), a ground photo, documents this transition.

The effect of an increase in weight of forbs from 140 kg/ha (transect 2A) to 516 kg/ha (transect 4) can be seen by comparing the Landsat imagery in these areas. The weights of grasses and litter along these transects are essentially the same: 633 and 704 kg/ha for the wet weight of grasses and 580 and 624 kg/ha for the wet weight of litter. But on the Landsat imagery, the area through which transect 4 runs is considerably more reddish, which can be attributed to increased infrared reflectances (Landsat MSS band 7) caused by the additional green forb vegetation.

In summary, for the Mixed Grass Prairie around the Little Bow Reservoir the light tones on the DCS imagery correspond to ranges with less biomass (reduced by cattle utilization or associated with poor-quality sites) and the darker tones with good range condition. In addition, if the carryover had been decreased by heavy utilization, the near-infrared reflectivity of the green vegetation was increased, no matter how short the green vegetation, as long as it covered most of the ground surface. Consequently these areas appeared pinkish on the imagery. Examples of imagery from three other areas will now be presented to substantiate these findings.

3.3.2 Vauxhall

The Vauxhall area is approximately 60 km southeast of Little Bow and is characteristic of the more arid parts of the Brown Soil Zone. The area is described in Section 2.2.2. A July 26, 1980 image was chosen for comparison with the results of the ground investigation (Figure 3(a)). At this time of the year, there is very little green vegetation except in the odd depression, which appear as reddish pink dots on the imagery. As in the Little Bow Landsat enhanced colour

composites, the darker blue tones correspond to the better range areas.

Figure 3(c) shows the fenceline contrast at A (Figure 3(b)) facing west. No quantitative clipping data were collected but a thorough subjective assessment was made of the area. The field on the left in Figure 3(c) had considerably more carryover and substantially less fringed sage than the field on the right. Even on the ground photograph the effects of shadowing caused by increased amounts of biomass are apparent in the darker tones.

Another area where there is a distinct contrast is at B (Figure 3(b)). The area to the south (Figure 3(d)) has a substantial amount of fringed sage and very little carryover from previous years. These two characteristics usually go hand-in-hand for, as a range degrades and the amount of the climax species decreases, invaders such as fringed sage become more prevalent. The silvery appearance of this plant is probably contributing to the lighter appearance of the low carryover fields. Figure 3(e), on the north side of the road at B, has more carryover, less fringed sage and consequently appears as a darker blue on the image.

Area C (Figure 3(b)) on this Landsat image is a depression with an exposed alkali patch that appears as a white patch on the imagery. This is illustrated in the ground photo in Figure 3(f).

At D (Figure 3(b)) on this image there is a good example of a manmade disturbance. A pipeline has been put through the area resulting in a disturbance on the ground approximately 7 metres in width (see Figure 3(g)). This is a good example of how objects smaller than the instantaneous-field-of-view of the sensor (which is about 80 metres) are vividly depicted on the imagery because of their high contrast with the surroundings. Other very evident cultural features are the pivotal irrigation patterns at E (Figure 3(b)).

3.3.3 Scandia/East Lomond

The areas operated by the Scandia Grazing Association on the east bank of the Bow River 10 km from the town of Scandia and the East Lomond lease west of the river are quite similar topographically to Little Bow/Travers. They have large areas of stable sand dunes and undulating to gently rolling terrain underlain in places by thick deposits of alluvial gravel.

Figure 4(a) is a June 29, 1980 image of the area. The rangeland in the northern half of the Scandia lease (area A in Figure 4(b)) is in poor to fair condition with a sparse vegetation cover, little carryover, and a prevalence of fringed sage and sagebrush. This area appears bluish white on the DCS images. Figure 4(c) is a ground photo taken of the area showing this lack of carryover and prevalence of sage. Cattle have concentrated near the lake for many years so that the southern part of the lease has not been heavily utilized. South of this lake beyond a ridge of stable sand dunes populated by sandgrass, rose, and golden bean, is a level sandy plain in good condition appearing as dark blue on the imagery (area B on Figure

4(b)). Figures 4(d) and 4(e) are ground photos of this area. The whitish areas at C and D on Figure 4(b) are a gravel pit and the remains of a sheep ranch where the grass is extremely sparse and short so that a great deal of bare soil is exposed. As mentioned previously, crested wheatgrass has a very distinctive spectral reflectance and appears as dark greenish tones on the enhanced colour composite imagery. A small patch of this vegetation type occurs at E on the Landsat image.

On the western side of the Bow River is the East Lomond lease. This lease is divided into several large pastures, each approximately 500 hectares in area. Cattle are put onto the lease at F in spring, usually the beginning of May, and moved south during the grazing season until October. This area is heavily utilized as the cattle concentrate here after being placed upon the lease. The poor range appears light blue on the DCS imagery. The light and dark tones on other parts of the lease are most illuminating as they indicate that the cattle generally concentrate on the west sides of the fields and in the corners near the fences. This was confirmed by Jake Willms, Public Lands Division, Alberta Energy and Natural Resources, who is responsible for inspection of the lease. Large areas of the lease have been underutilized in the past (darker tones on the imagery) primarily because an available water supply is lacking. To illustrate the appearance on the ground of several light and dark areas on the DCS imagery, consider Figures 4 (f), 4(g), 4(h) and 4(i), which were taken at location H. Figures 4(f) and 4(g) show the east side of the pasture, with very little carryover, and considerable amounts of pasture sage and shrubs. In fact, from the closeup of the area, it can be seen that there is very little grass, and hence the satellite is imaging mostly little club moss. By contrast, the ground photos looking to the west from this point (darker tones on the Landsat image) show more standing grass and less sage. This is consistent with all the evidence to date that the darker tones on the Landsat image can be associated with better pastures with greater amounts of standing brown biomass and lesser amounts of forbs, shrubs and sage.

Several other interesting features are apparent on the Landsat DCS imagery. A large area of eroded solonetzic soils is seen at I on Figure 4(b). The white dots are prominent blowouts and saline depressions. As well, darker toned scattered curved patches (J on Figure 4(b)) are ridges of stable sand dunes populated by vigorous growth of sandgrass and rose.

The DCS Landsat colour composites have proven to be a reliable indicator of range condition. Since Scandia/East Lomond was not one of our major test areas, we do not have ground clippings to quantify the above qualitative field assessment.

3.3.4 Bow Island

Figure 5 is an August 30, 1980 Landsat MSS enhanced colour composite of the Bow Island Grazing Lease. As in all the previous examples, the darker tones correspond to better range condition. However, in addition, several distinctive features are noteworthy. For example, area A on Figure 5 is a field that has been extensively

grazed for the last three years under a range management practice of grazing three years and then allowing the land to recover for three years with no grazing. The third year of grazing was 1980 and the pasture definitely appears on the imagery to be overutilized.

The next feature illustrates the need to be familiar with the area in order to optimally interpret the imagery. At area B (Figure 5), there are fields of planted Russian wild rye, which appear mottled light blue on the imagery. These grasses are planted in rows and do not spread out greatly with the result that a large amount of soil is imaged. From the imagery such fields are difficult to label according to range condition.

3.4 TIME SEQUENCE

One of the important considerations for a rangeland manager using remotely sensed data in an operational mode is when to acquire the data. In many applications, the answer is obvious, but in rangeland this is not the case. Should the imagery be acquired in the fall after the cattle have been taken off the range, in the summer at the peak of green, or at some other time coinciding with movement of cattle between range areas? The effects of changes over the growing season were evaluated by making field observations and measurements and examining Landsat-enhanced imagery of the Vauxhall, Alberta lease for the following dates:

(a) June 26, 1979
(b) September 26, 1979
(c) June 29, 1980
(d) July 26, 1980
(e) August 30, 1980
(f) October 23, 1980

These are shown in Figures 6(a), 6(b), 6(c), 6(d), 6(e) and 6(f) respectively. In the Mixed Grass Prairie, plant growth begins relatively early in the spring and continues until midsummer when seasonal moisture deficiencies induce dormancy in the grasses. If the carryover from the previous season has been thick and upright, it will tend to obscure the green vegetation even when maximum growth has been attained. It can be seen from the images that the rangelands did not change markedly over the growing season. However, vegetation associated with moister areas changed from pink to blue as water bodies and depressions dried over the summer and the vegetation became less vigorous. Also, areas dominated by forbs or shrubs, which were pink or red during the growing season, turned blue as the vegetation lost its leaves.

This would imply that the general range condition is not a rapidly varying parameter under "normal" rangeland management practices. If there is nothing to attract cattle to an area where there is heavy carryover in one particular year, this will, in general, be the case the next year. The range inspectors at the Lethbridge Office of the Public Lands Division, Alberta Energy and Natural Resources suggested that they would prefer two images. The first would be in the fall mainly to assess the amount of carryover

without the competing effects of green versus brown matter on Landsat MSS band 7 reflectance and the other early in the growing season. Of course, if one wishes to assess the effects of changes in rangeland management practices, appropriately timed data acquisition must be carried out.

3.5 CONCLUSIONS: DEMONSTRATION COMPONENT

The demonstration component led to the development of a digitally contrast stretched Landsat image product that provides useful information to range managers. Evaluation of these image products by the field staff of the Lethbridge and Medicine Hat offices of the Public Lands Division, Alberta Energy and Natural Resources, showed that the tones on the image could be interpreted in terms of range condition. It was generally found that areas that were characterized by heavily utilized grasslands with little carryover or litter and short vegetation forming an almost continuous green ground cover appeared as pink tones mixed with patches of blue on the imagery. Brighter pink tones corresponded to denser forbs and shrubs. Good to excellent range associated with abundant grass cover and large amounts of carryover and litter appeared as dark blue. The determination of range condition from the same Landsat product was not as reliable in the Rough Fescue Prairie.

In addition to the general information on range condition, the imagery is also useful for monitoring other features of interest to range managers. For example, saline patches and large dugouts are easily observed. Manmade disturbances such as pipelines and well sites can also be seen.

Full utilization of information contained in the satellite data requires a detailed knowledge of the range or lease under investigation. The manager who is familiar with a particular area can use his experience to properly interpret anomalies on the imagery. For example, correct interpretation of crested wheatgrass or Russian wild rye pastures can be assured only by the experience of the range manager. These species are planted in widely spaced rows in the Mixed Grass Prairie but the crested wheatgrass can become quite dense and expand to reduce the amount of exposed soil whereas Russian wild rye does not. The mottled light blue appearance on the Landsat imagery of the Russian wild rye is partially due to the satellite sensors imaging this exposed soil. By contrast, crested wheatgrass appears as a dark bluish green as little soil background is present. The fact that the range manager can interpret and utilize the data himself makes the digitally stretched image a more powerful tool than a classified image data product.

We found that the requirements of the range managers were best met by a standardized image product. For the Mixed Grass Prairie of southern Alberta, one or two images per season appear to be sufficient for management action. The range managers need an image in early summer when they first go into the field and one towards the end of the grazing season. Since most of the lease assessment is done in terms of range condition, rather than quantitative biomass estimates, the qualitative interpretation approach was found sufficient for most management needs.

Finally, the success of the demonstration component clearly showed the importance of the project structure. The close interaction of the field staff and the remote sensing specialists was an essential factor in the success of the project. From the beginning, the needs of the range managers were assessed and the satellite data were developed to meet them. Another factor was the identification of the demonstration and research and development as two related but separate components. This meant that practical data products could be evaluated in the field while, at the same time, the research was providing improvements and new products. The combination of the interaction of the research with the demonstration and the close working relationship with all levels of the user agency proved a very effective mechanism for the development and transfer of satellite technology to the operational mandate of the user agency.

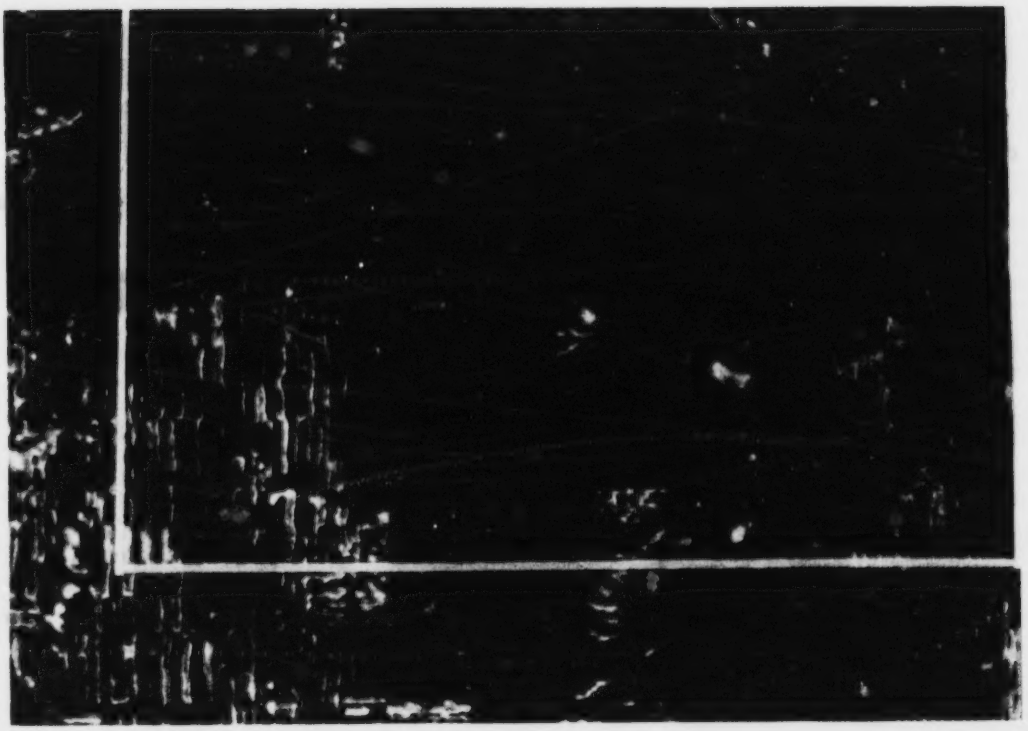

FIGURE 2(a): Digitally contrast stretched (DCS) image of the Lake Travers - Little Bow intensive test area, July 8, 1980. Yellow border indicates border of Figure 2(b).

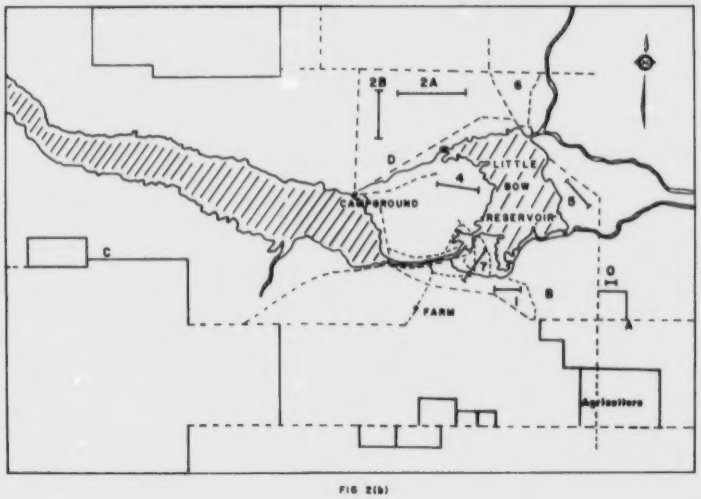

FIGURE 2(b): Key to Figure 2(a) showing location of transects 0-7.

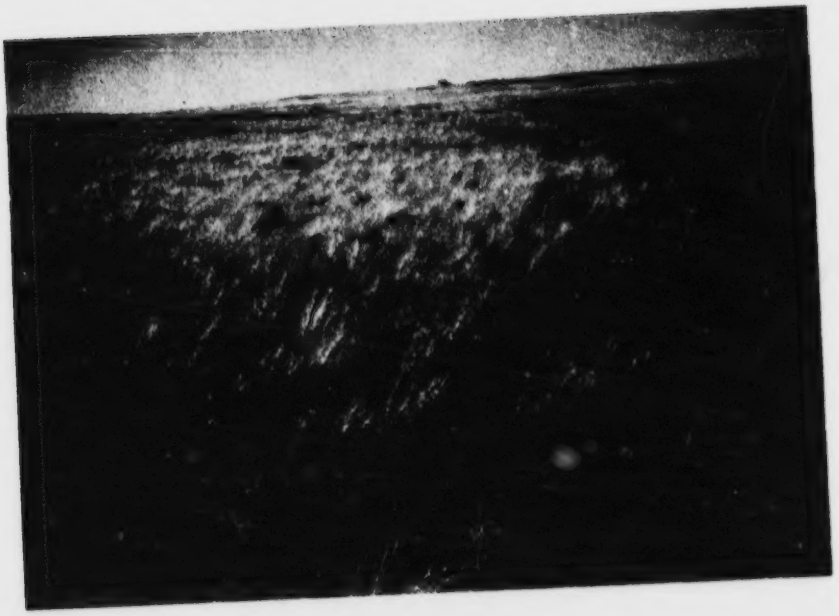

FIGURE 2(c): Area of range in excellent condition looking north from location A in Figure 2(b).

FIGURE 2(d): Area of range in fair condition looking south from location A in Figure 2(b).

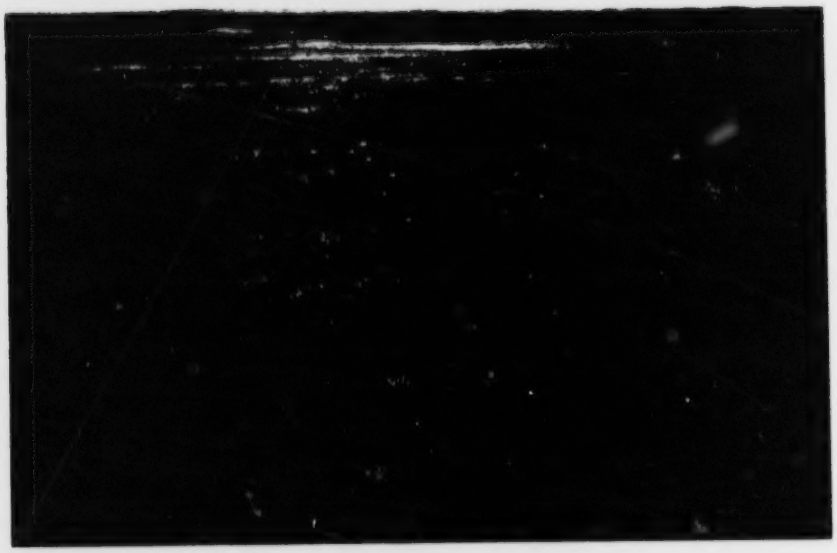

FIGURE 2(e): Area of range in fair condition looking north from location B in Figure 2(b). The presence of forbs, particularly in patches such as in the foreground, cause the pink to red mottles seen in the DCS Landsat image south of the Little Bow Reservoir (Figure 2(a)).

FIGURE 2(f): Area of crested wheatgrass in excellent condition in pasture to the west of C in Figure 2(b).

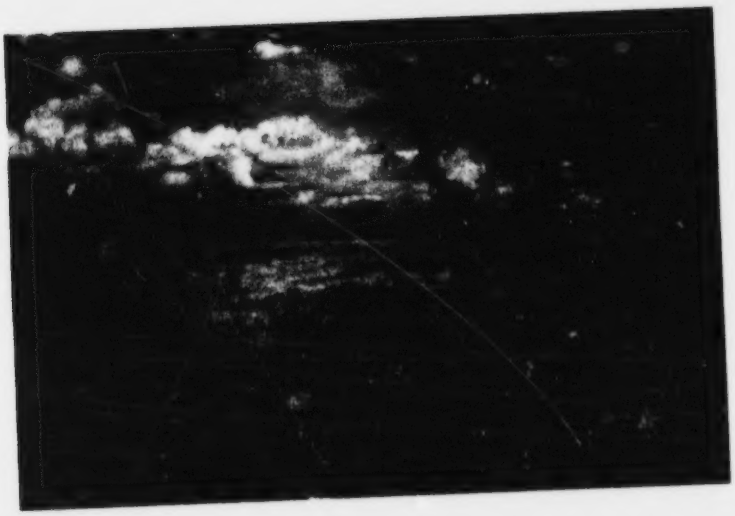

FIGURE 2(g): Area of dense fringed sage near C in Figure 2(b).

FIGURE 2(h): DCS image of Lake Travers - Little Bow intensive test area, July 26, 1980. Note decrease in redness south and west of Little Bow Reservoir as vegetation senescence occurs.

FIGURE 2(i): Photo taken near D (facing north) in Figure 2(b) showing the transition between an area of crested wheatgrass (yellow - orange) and native rangeland invaded by fringed sage (blue-gray). This transition can be seen on the July 26, 1980 DCS image (Figure 2(h), in which the crested wheatgrass areas are darker.

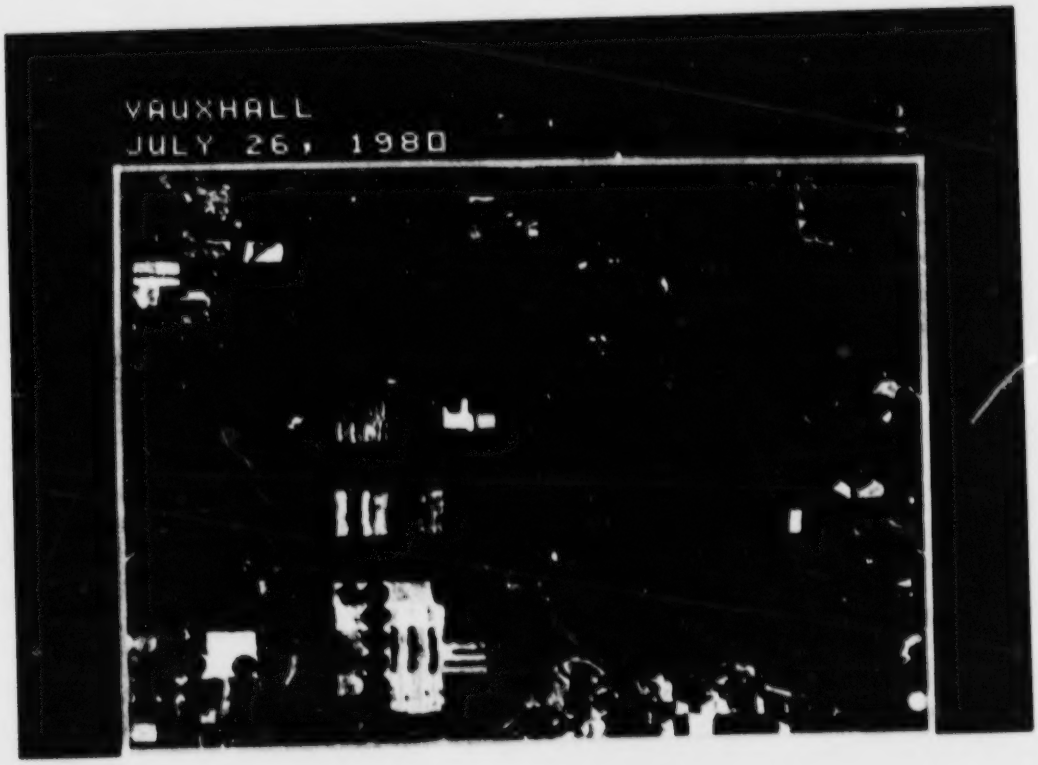

FIGURE 3(a): Digitally contrast stretched (DCS) Landsat image of the Vauxhall test area, July 26, 1980.

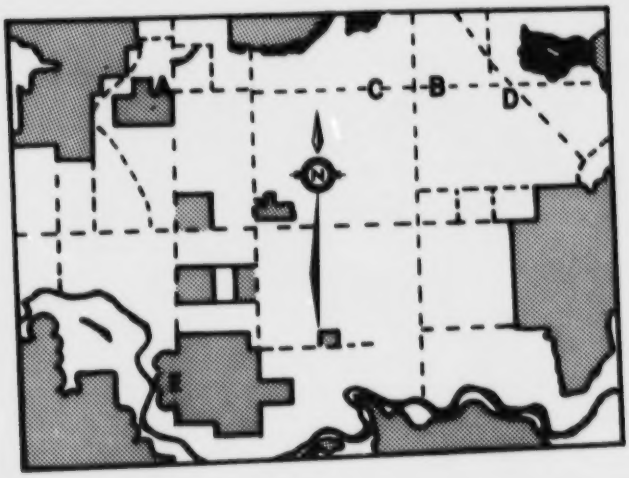

FIGURE 3(b): Key to Figure 3(a).

FIGURE 3(c): Fenceline at A in Figure 3(b), facing west. Note how the area in better condition to the south is darker on the DCS image than the poorer area to the north.

FIGURE 3(d): Poorer area facing south from B in Figure 3(b).

FIGURE 3(e): Better area facing north from B in Figure 3(b).

FIGURE 3(f): Alkali patch at C in Figure 3(b).

FIGURE 3(g): Ground disturbed for pipeline at D in Figure 3(b).

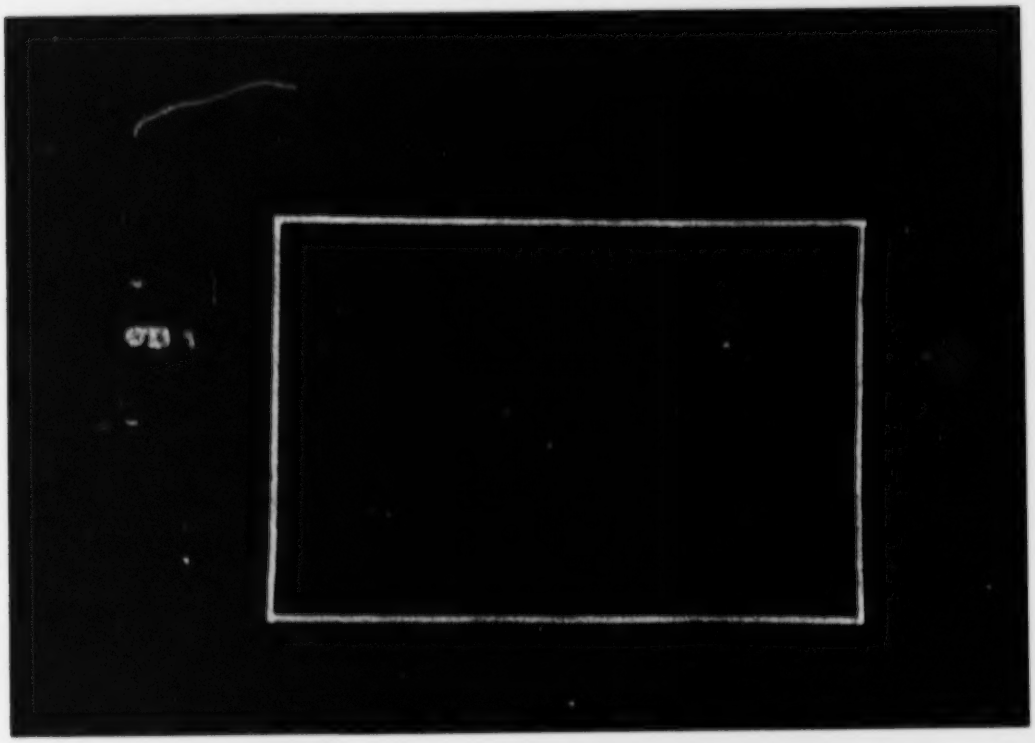

FIGURE 4(a): Digitally contrast stretched Landsat image of the Scandia and East Lomond leases, June 29, 1980. Yellow border indicates border of Figure 4(b).

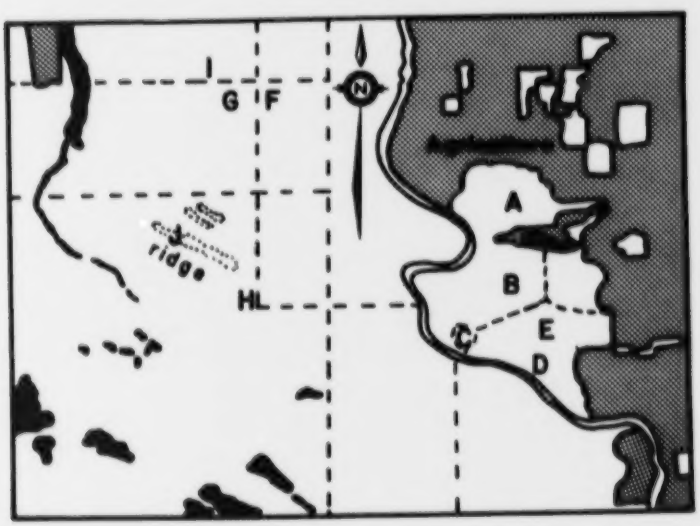

FIGURE 4(b): Key to Figure 4(a).

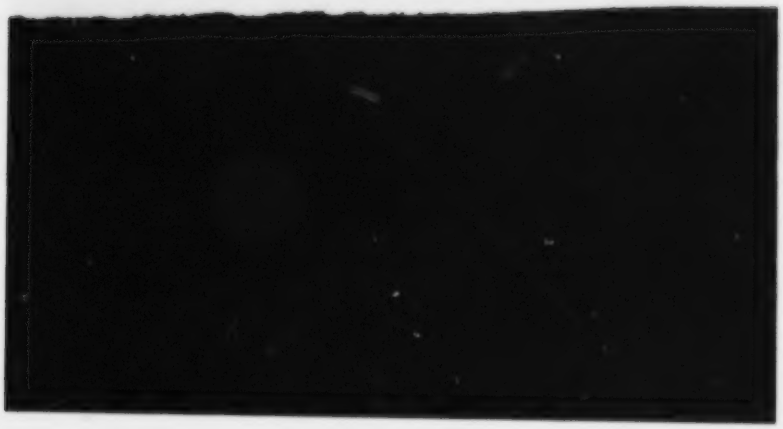

FIGURE 4(c): Range in poor to fair condition at area A in Figure 4(b).

FIGURE 4(d): Range in good condition at B in Figure 4(b).

FIGURE 4(e): Closeup of area B in Figure 4(d).

FIGURE 4(f): Area of range in fair condition east of H in Figure 4(b).

FIGURE 4(g): Closeup of the area east of H in Figure 4(f).

FIGURE 4 (h): Area of range in better condition west of H in Figure 4(b).

FIGURE 4(i): Closeup of the area west of H in Figure 4(b).

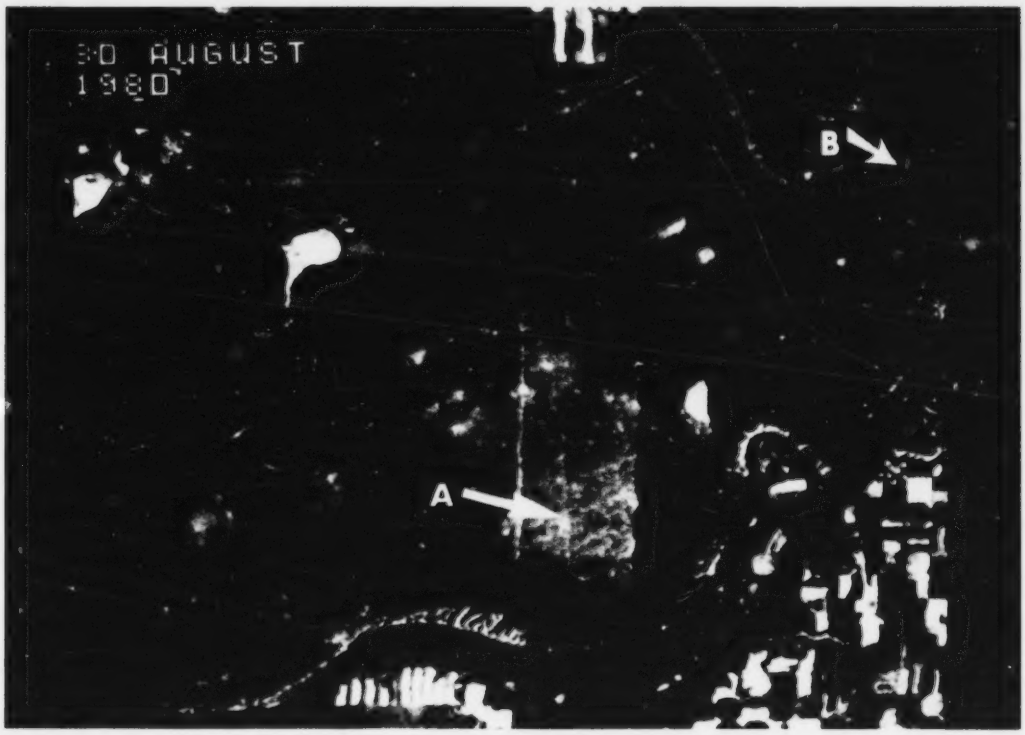

FIGURE 5: Digitally contrast stretched Landsat image of the Bow Island grazing lease, August 30, 1980.

A. Heavily utilized pasture. B: Area planted to Russian wild rye.

FIGURE 6: Time sequence of image of the Vauxhall lease.

(a) June 26, 1979.
(b) September 26, 1979.
(c) June 29, 1980.
(d) July 26, 1980.
(e) August 30, 1980.
(f) October 23, 1980.

FIGURE 6(a)

FIGURE 6(b)

FIGURE 6(c)

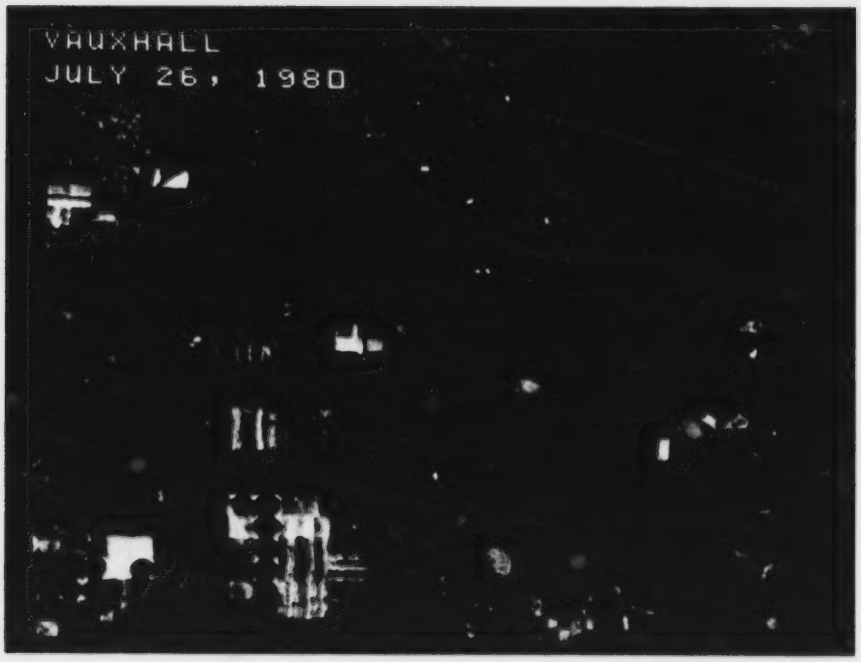

FIGURE 6(d)

FIGURE 6(e)

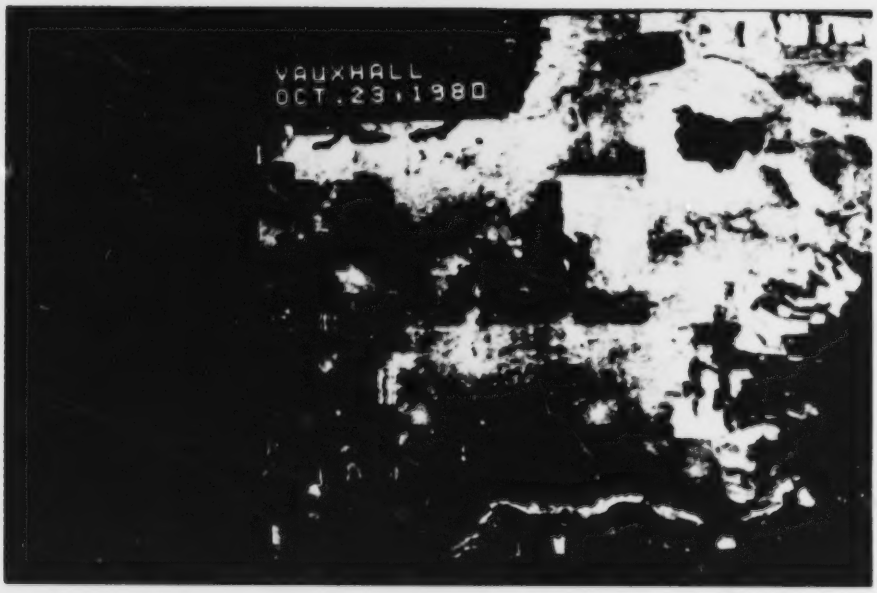

FIGURE 6(f)

4. RESEARCH COMPONENT

At the beginning of the project, our knowledge of remote sensing applied to rangeland was limited to a fairly thorough knowledge of the literature (summarized in Section 1.2), plus the experience of Thomson et al. (1980) in the improved pastures in the Gray Wooded Soil Zone of Saskatchewan, and the experience of Pearce (1980) in the Mixed Grass Prairie of southeastern Alberta.

Any biomass estimate provided by remote sensing must be both accurate and reliable when used in an operational system. To achieve accuracy, a relationship between biomass and a remote sensing measurement must have a high coefficient of determination (0.8 or higher) so that sources of variation that are not accounted for do not cause large errors. The conditions under which the biomass relationship apply must be well known, so that the method is not used in circumstances when it will not work. Finally, any quantitative biomass estimate must distinguish between desirable biomass (grasses) and undesirable biomass (forbs, shrubs and trees). As mentioned in Section 1.2, many investigators have shown quantitative relationships between rangeland biomass and the reflectance factor in single bands or combinations of bands, but we are not aware of any present work that satisfies all of the above conditions for accuracy and reliability.

The two major objectives of the research and development component of this project were to determine:

(1) the extent to which remote sensing methods can provide qualitative information on range condition and quantitative information on green, brown and total biomass for rangeland management; and

(2) to what extent future satellite sensors such as the thematic mapper on Landsat-D would be able to supply better information for rangeland management.

From these we were able to specify the following specific objectives:

(1) To determine whether there is a relationship between standing total biomass and spectral reflectances for rangeland types characteristic of the Alberta Mixed Grass and Rough Fescue Prairie with particular emphasis placed on the relationship between standing brown biomass and spectral reflectance.

(2) To determine whether there is a relationship between litter and spectral reflectances for rangeland types characteristic of the Alberta Mixed Grass and Rough Fescue Prairie; in particular, whether there is a difference between the litter and soil backgrounds for typical soils in the area.

(3) To determine how the relationships in 1 and 2 change throughout the growing season as the mix of green and brown standing matter changes.

(4) To determine whether grasses/forbs/shrubs and species composition changes can be detected to aid in assessment of range condition.

(5) To assess the contribution of the thematic mapper bands to monitoring seasonal changes in rangeland condition.

We have been able to meet all of these objectives in this project.

4.1 EXPERIMENTAL DESIGN AND DATA COLLECTION

An experiment was designed using CCRS V-IR Spectroscopy Laboratory (Brown and Ahern, 1980) and based on results from the Saskatchewan Rangeland/Rapeseed Study and Pearce's M.Sc. research (Brown et al., 1980; Thomson et al., 1980; Ahern et al., 1980; Pearce, 1980).

Measurements were made at the three intensive study areas: Little Bow/Travers Reservoir, Ross Lake, and the Agriculture Canada Range Research Substation near Stavely. The biophysical characteristics of these test areas are described in detail in Section 2.

A two-faceted approach was taken in the study of these three areas: each area was visited once a month from June to September by the CCRS V-IR Spectroscopy Laboratory, when spectral measurements and detailed ground sampling were carried out. In addition, each test area was mapped on the ground and the biomass sampled each month over a wider area for comparison with Landsat and airborne multispectral scanner imagery.

4.1.1 Measurements of Spectral Reflectance Factor

Measurements of the spectral reflectance factor were made with a Spectrascan Ltd. (of England) SP 2000 reflectance spectrometer (formerly designated the RVNT/B). The details of this instrument and its calibration are given by Brown and Ahern (1980). For this project, the reflectance factors of five independent targets, each 50 cm x 50 cm, were measured from a height of 4 m above the ground. These reflectance factors were measured at 10 nm intervals over the range 0.36 to 1.0 micrometre and at 20 nm intervals over the range 1.0 to 2.4 micrometres. The viewing angles of targets 1 to 5 were, respectively, -14^{o}, -7^{o}, 0^{o}, 7^{o} and 14^{o} relative to nadir. The scan azimuth was generally in a direction perpendicular to the solar azimuth to minimize viewing angle effects (Staenz et al., 1981). A larger field of view would have been preferable to average spatial variability, but this would have made the task of clipping the measured area for biomass measurements too time consuming. The biomass in targets 1, 3 and 5 was clipped and separated into several categories (see Section 4.1.1.2 for details).

4.1.1.1 Range Characteristics: Visual

One of the most important aspects of a remote sensing spectroscopy study is to obtain as much relevant information as

possible about the object under study. This is particularly true in the case of rangeland, where there can be so much variability in species composition, moisture condition, and state of growth. Exclusive of the weights of various biomass components, which will be discussed in Section 4.1.1.2, the following observations and measurements were made of the range areas measured by the spectrometer:

Observer and date
Measurement location
Visual estimate of percentage of green, of litter, of bare soil and of carryover. For the purposes of this study, standing brown grass is considered to be carryover and fallen and decomposing brown biomass is considered to be litter.
Soil moisture at depths of 2 cm and 15 cm
Species composition, with dominant species noted

The soil moisture was measured with a resistance meter built by Mr. Steven Fudge of the University of Calgary, following the plans of Graf (1973).

4.1.1.2 Biomass Sampling

Biomass sampling in support of the spectroscopic observations was carried out with the aid of a specially designed 0.5 m by 2.5 m sampling frame, which was divided into five 0.5 m by 0.5 m areas corresponding to the five independent targets viewed by the spectrometer. The biomass sampling was carried out for targets 1, 3 and 5 immediately after the spectral measurements were taken. In each target outlined by the sampling frame, the forbs were first picked at ground level and put in a paper bag. Next, the standing carryover was removed by combing it from the standing green vegetation by hand. Then the (fallen) litter was gathered by hand and finally the remaining green grass was clipped and bagged. In June, there was no attempt to separate the litter and carryover. Although the manual combing generally separated the brown carryover, which was not firmly rooted, from the firmly rooted green grass, there was invariably some mixing of green grass into the carryover bag and vice versa. The full bags were immediately labelled and weighed. The bags were then transported to the Agriculture Canada Lethbridge Research Station for drying and reweighing.

Immediately preceding the V-IR Spectroscopy Laboratory measurements, a vertical photograph was taken on Kodachrome 64 film with a 35 mm camera attached to the spectrometer. This photograph included the sampling frame so that the five targets could be accurately delineated. Vertical photos of targets 1, 3 and 5 were taken from eye level along with another photograph of the general vicinity. This photography proved to be very valuable in subsequent interpretations of the spectroscopic data.

For the field surveys in support of Landsat and airborne MSS data, the biomass sampling was done on four to seven linear transects covering representative areas of different sites within each test area. From ten to fifteen samples were obtained on each transect.

The sampling was done with a 0.25 square metre frame on the Mixed Grass Prairie and with a 1 square metre frame on the Fescue Grasslands (Ross Lake and Stavely) to help average out the variability caused by the 30 to 50 cm clump structure. These sampling quadrats were selected on the basis of subjective evaluations of the degree of "representativeness" of the range area. Although this subjective selection can impart a degree of bias to the data, the lack of available manpower necessitated this mode of collection. Harlan et al. (1979a) reported that, in their research on rangelands in Colorado and West Texas, 100 sample quadrats per site, chosen randomly, were still not sufficient to take into account the extreme heterogeneity of plant biomass. This heterogeneity has also been noted by others (Carneggie et al., 1979; Driscoll, 1974; George et al., 1977; Maxwell, 1975; Salmon-Drexler, 1977; and Watson, 1977).

Information collected on the vegetation included the identification of both dominant and associated species, biomass, growth stage, and visual estimates of the foliage cover of the green vegetation, the carryover and litter, and the amount of exposed soil. The dominant and subdominant grass species were used to characterize the vegetation types.

Biomass sampling was done following the procedures described above for the spectroscopic measurements.

Surface soil colour (compared with Munsell Colour Chart), texture, and soil moisture, as well as percentage of exposed soil and evidence of erosion or salt accumulation were recorded with the vegetation measurements. A colour photograph was taken of each area sampled for a visual record of ground conditions during each measurement period.

4.2 DATA REDUCTION AND INTERPRETATION OF THE GROUND SPECTROSCOPIC MEASUREMENTS

As soon as the data were returned from the field, the 35 mm film was processed, mounted on slides, and annotated. The cassettes containing spectral reflectance measurements were copied to disk and displayed on a graphics terminal, where hard copies were made. The photos and spectral tracings were inspected to assess data quality, provide an initial look at the results and ensure that no important information would be lost by limiting subsequent analysis to the reflectance factors in the first six thematic mapper bands (see Section 4.2.4 and Table 4). These inspections provided valuable initial information to develop an understanding of the spectral reflectance of various vegetation and soil mixtures and to guide subsequent analysis.

Two types of ancillary variables were added to these spectral data: those particular to a given measurement location, called plot parameters, and those specific to each target, called target parameters. The plot and target variables are listed in Table 3.

4.2.1 Calculation of Band Reflectances

Several studies have shown that the thematic mapper bands cover the biophysically important regions of the reflectance spectrum of vegetation, and that bands TM3, TM4, and TM5* are a good three-band subset (Tucker, 1978b; Staenz et al., 1980).

The reflectance factors for bands TM1 through TM6 (Table 4) were computed by integrating the reflectance spectra between the lower and upper wavelength for each band. The ancillary data (plot and target parameters) were combined with the band reflectances to produce new files of greatly reduced data volume. These files were copied from the V-IR Lab PDP 11/10 minicomputer to the CCRS PDP KL-10 timesharing system for subsequent analysis.

4.2.2 Two-Dimensional Scatter Diagrams

One of the more informative means of analyzing the spectral reflectance data is to create two-dimensional scatter diagrams showing the measurements in a way in which the individual points can be identified. Figure 7 is an example of such a plot. A manual cluster analysis was performed by circling groups of points having similar biophysical characteristics. This allows one to obtain a feeling for the spectral separability of the various classes.

Of course, there are many two-band combinations to choose from. However, previous work (Staenz et al., 1980) has shown that for vegetation, thematic mapper bands 1, 2 and 3 are highly correlated, as are bands 5 and 6. The correlation analysis performed on the present data set also shows these band pairs to be highly correlated (Tables 8-10). Therefore, a three-band subset, such as TM3, TM4 and TM5, contains most of the spectral reflectance information in the data.

In the particular example shown in Figure 7, obtained at the Little Bow test area in July, we see that there is good separability among the various biophysical classes in bands TM3 and TM4. This separability is also evident on June 29 and July 8 Landsat MSS DCS images produced from similar bands (MSS4, 5 and 7) as part of the demonstration component of this project. The reflectance factor in both the red (TM3) and near-infrared (TM4) decreases as the amount of grass and litter plus carryover biomass increase. This is discussed in more detail in Section 4.2.6.1. We also see that the crested wheatgrass sample is dark in the red and the darkest of all classes in the near-infrared, as in the DCS Landsat imagery. Finally, areas with larger amounts of green vegetation are bright in the near-infrared and dark in the red, thus appearing pink to red in this DCS imagery.

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*In this report we will refer to the thematic mapper bands as TM1 through TM6 and the Landsat MSS bands as MSS4 through MSS7.

4.2.3 Interpretation Guide for Contrast-Enhanced Colour Imagery

Two-band scatter plots for each test area and for each month (June-September) have been produced for TM2 versus TM3, TM3 versus TM4, and TM3 versus TM5 and the individual vegetation/condition classes have been identified in each (Figure 7). These plots in turn can be used to predict the approximate colour of the biophysical classes on a DCS image, if the transformation between reflectance and gray level is known for each band. This is the case for our DCS Landsat MSS imagery (see Section 3.2) where green reflectance (MSS4 or TM2) in the range 2% to 24% is displayed as blue, red reflectance (MSS5 or TM3) in the range 2% to 24% is displayed as green, and near-infrared reflectance (MSS7 or TM4) in the range 12% to 30% (June-August) or 8% to 28% (September) is displayed as red.

Figure 8 is a colour prediction diagram for a colour image produced by an image recorder on which the green and red reflectance scale (displayed as blue and green) runs from zero intensity corresponding to 2 percent reflectance factor and full intensity (255 on an eight-bit scale) corresponding to 24 percent reflectance factor. The infrared reflectance scale (displayed as red) runs from zero intensity corresponding to 12 percent reflectance factor to full intensity corresponding to 30 percent reflectance factor. The rangeland classes outlined in Figure 7 have been replotted in Figure 8.

Tables 5, 6 and 7 summarize the findings derived from a study of the scatter plots, the ground photography, and the field notes, and predict the appearance of various rangeland classes throughout the growing season based on their measured spectral reflectance factors. The results have been checked against the DCS imagery produced from Landsat MSS bands 4, 5 and 7 and they agree quite well. In particular, the ground spectroscopic measurements confirm the relationship between image brightness and range condition in the Mixed Grass Prairie, predict the appearance of areas with a large amount of green vegetation, and confirm the inability of imagery made from green, red, and infrared measurements to discriminate range condition in the Fescue Prairie. The most apparent difference between the predicted colours and the actual imagery is an overall blue cast in the imagery in the areas predicted to be gray, as in the area around transect 5 (Figures 2(a) and 2(b)). In this case, the cause may be increased sensitivity of the film in the blue beyond that of the human eye, making the photographic image appear bluer than the image on the colour display screen.

Variations in photographic processing and other factors can cause other colour changes relative to the predictions, but these are easy to compensate for mentally if they are not too severe.

Figures 9 and 10 give a graphical indication of which rangeland classes can be distinguished in DCS imagery. In each figure, the various rangeland classes identified in each study area are indicated. Solid lines are used to indicate which classes are distinguishable and which are confused as the growing season

progresses. Confusion between classes is indicated by bringing the lines of the confused classes together. Figure 9 refers to the usual colour infrared composite with green reflectance displayed as blue, red reflectance displayed as green and near-infrared reflectance displayed as red. Figure 10 refers to a new colour composite with red reflectance displayed as blue, near-infrared reflectance as green, and reflectance in the 1.55 to 1.75 micrometre window (TM5) as red. This indication of separability is based on a subjective assessment of separability in the two-band scatter plots and the reflectance ranges presented in Tables 5 to 7. It has been verified as accurate where Landsat MSS or simulated thematic mapper images are available (see Section 4.3).

In the Mixed Grass Prairie, the various classes can be well separated until the onset of senescence using the green-red-infrared combination. In the Fescue Prairie, very poor areas, and areas of dense forbs and/or shrubs can be separated throughout the growing season with the green-red-infrared combination, but the rangeland classes from fair to excellent are blended together. The red-infrared-TM5 combination, however, appears to provide better separability, especially at the time of senescence. Unfortunately, the planned September airborne MSS flight did not occur, and this prediction has not yet been tested with actual imagery. However, thematic mapper simulation imagery obtained in July did show better separability with the red-infrared-TM5 combination than with the green-red-infrared combination (see Section 4.3).

4.2.4 Correlation Analysis

Correlation and regression analyses were performed to investigate whether further relationships were present in the data. The correlation analysis was performed with the Western Michigan University STP package. Tables 8 to 10 are matrices of correlation coefficients for the three test areas for each of the four months. Although the number of correlation coefficients presented in these tables is rather formidable, the results of a careful inspection can be summarized briefly:

(1) Correlation amongst the reflectance factors in bands TM1, TM2, and TM3 is very high. Similarly, a high correlation exists between the reflectance factors in bands TM5 and TM6. This was true for all the test areas and for all months. In most cases, the coefficient of correlation (r) is greater than 0.9, although between TM5 and TM6, it drops below 0.8 by the end of the growing season at Little Bow and Stavely. This is in accordance with previous results for cultivated crops (Staenz et al., 1980) and indicates that most of the information about rangeland is present in a three-band subset of the first six thematic mapper bands.

(2) The correlation between thematic mapper band reflectance factors and quantitative biomass measurements is generally below 0.8. This will be discussed at length in Section 4.2.5.

(3) Correlation between the weight of grass and the weight of litter and carryover is generally high. There is generally low, and often negative, correlation between the weight of forbs and the weight of litter and carryover. This is because (a) rangeland in good condition will produce a high weight of grass, at least 50% of which will remain as carryover and litter in subsequent years, and (b) an increasing weight of forbs can be associated with deteriorating range condition.

(4) The weight of carryover is generally highly correlated with the weight of litter, but there are sufficient exceptions, particularly in the Mixed Grass Prairie, to justify measuring these two quantities separately.

(5) The average soil moisture at two depths (2 and 15 cm) is not highly correlated with any other variables. Since the long-term average soil moisture is known to be strongly related to range productivity (Smoliak et al., 1976b), this instantaneous measurement of soil moisture at these depths must have too much temporal variability to reflect the long-term average.

In correlation analysis results that are not shown in Tables 8 to 10, we have also determined that the wet and dry weights are highly correlated, and the correlation between band reflectance factors and biomass weights is generally slightly higher with wet weights than with dry weights.

We have also found that visual estimates of percentage of green, of carryover, and of litter are not highly correlated with thematic mapper band reflectance factors. We made these estimates on the assumption that the reflectance factors might be more closely related to the percentage of green ground cover in the field of view than to sample weight measurements. However, random and systematic errors in these obviously rough, subjective estimates seem to have introduced enough scatter to negate the value of these measurements.

4.2.5 Quantitative Biomass Estimate

A reliable quantitative estimate of rangeland biomass that could be derived from remote sensing measurements would be valuable in assessing range condition, productivity, and carrying capacity. As discussed in the literature review (Section 1.2), a great deal of effort has gone into attempting to develop such biomass estimates, and quite promising results have been reported.

We attempted to derive quantitative relationships between various types of biomass (e.g., grass, forbs, litter, carryover) and the reflectance factor in thematic mapper bands 3 to 6. Bands TM1 and TM2 were not assessed because of their high degree of correlation with TM3. In addition, because of atmospheric scattering, the contrast in these bands is reduced when viewed from space, making TM3 the band of choice. As in most of the studies to date, the method used was bivariate and multivariate regression analysis.

4.2.5.1 Linear Regression Analysis of Ground Based Data

The coefficients of determination (r^2) obtained from linear regression analysis of the data from the three test areas are presented in Tables 11 to 13. Although in many cases the correlation is not significant at the 1% or 5% level, the slopes of the regression relationships have indicated a consistent qualitative relationship between green and brown biomass and spectral reflectance. See Section 4.2.5.2 for further discussion of this point.

In nearly all cases, the correlation is negative, that is, the band reflectance decreases as the independent variable increases. In the few cases of a positive correlation, the coefficient of determination is preceeded by (+). The sample size and upper and lower limits of the independent and dependent variables are also given.

Inspection of Tables 11 to 13 shows that no single band is capable of estimating any type of biomass with a coefficient of determination greater than 0.8, which was one of our reliability criteria. The 0.8 value results from including measurements where green vegetation nearly fills the IFOV of the spectrometer. This does not occur in other months or for Landsat MSS. A nonlinear multivariate model might lead to better results but far more samples, obtained in a truly random fashion, would be necessary to establish it. Furthermore, the resulting model would undoubtedly be valid only for a relatively short phenological window before re-evaluation to establish new coefficients would be necessary because of the temporal changes in the relative amounts of green and brown biomass.

Nonetheless, a careful study of the scatter diagrams produced in conjunction with the regression analysis, together with a study of the reflectance spectra and two-band scatter plots has produced a greater understanding of the spectral reflectance of typical rangeland areas. The results of this study are summarized in Tables 5 to 7 and in Appendix B.

4.2.5.2 Quantitative Analysis of Landsat MSS Data

An alternative approach, using Landsat MSS data, was taken to see if there is a quantitative relationship between biomass and remotely sensed data. The average biomass values obtained from clippings along the transects at the three test areas were compared with the digital MSS data.

The Landsat MSS intensities were determined using the CCRS Image Analysis System (Goodenough, 1979). These intensities along each transect were correlated with the biomass values. The coefficients of determination and other relevant information from this analysis are presented in Tables 14 through 16.

Once again, the coefficients of determination are too low to provide encouragement that a method of reliably estimating quantitative biomass from Landsat MSS data would be easily obtainable. In addition, the small number of samples does not warrant a high degree of statistical confidence in the results. The high values of the coefficient of determination in the relationships between the weight of grasses, litter, and total biomass, and the MSS band reflectance values for Ross Lake are misleading because there is only one data point for a high biomass area while the others are for low biomass areas.

This is not to say that the relationships between biomass and MSS band reflectances indicated in Tables 14 through 16 are not real. They are entirely consistent with both our qualitative understanding of the Landsat imagery based on extensive field checking, and with the results of our ground-based spectroscopic studies. However, far more ground transects would be required to determine the existence of a sufficiently accurate relationship between biomass and reflectance to give confidence that quantitative biomass estimates are feasible.

4.2.6 Further Discussion of Landsat MSS Results

In this section we will merge the results of the ground spectroscopic studies with the knowledge gained in comparing the Landsat MSS data with the ground transects.

4.2.6.1 Little Bow/Travers Reservoirs

The Little Bow data set represents the Mixed Grass Prairie ground measurements. The appearance of the satellite imagery along the various transects throughout this area is discussed in Section 3.3.1.

For the Mixed Grass Prairie, as represented by Little Bow, the relationships noted at One Four by Pearce (1980) do hold. Light tones on the Landsat imagery correspond to ranges with less biomass (reduced by cattle utilization or associated with poor-quality sites) and darker tones with good condition range and the desirable ratio of green grass, carryover, and broad-leafed plants. In addition, we observed by heavy cattle utilization, the red reflectivity of the vegetation was decreased (no matter how short the green vegetation as long as it covered most of the surface) and these areas appeated pinkish on the imagery.

Both the Landsat imagery and the ground spectral measurements show that crested wheatgrass areas have darker tones, for the same biomass, than native rangeland. The spectroscopic data show a gradual decrease of contrast after July when the darker areas become brighter and the brightest areas (forb patches and dense green vegetation) become darker as the forbs lose their leaves and the grasses senesce. This is observed as an overall brightening and loss of pink and red tones in the DCS imagery, to the extent that for September, the reflectance limits in MSS7 for the digital contrast stretch had to be modified.

The comparison between the reflectance versus biomass relationships obtained with the ground spectroscopy laboratory and those obtained with the Landsat MSS and ground transect data shows a surprising anomaly for the July time frame. The Landsat and ground transect data (Table 14) show a strong relationship between the weight of litter plus carryover, and range reflectance, particularly in the infrared (MSS7). Conversely, the ground spectroscopy data show a weak relationship between the weight of litter plus carryover and range reflectance, particularly in the infrared (TM4). Instead, a strong correlation with green biomass (grass and forbs) is observed in the red region (TM3). An inspection of the scatter plots for these data has provided the explanation for this anomaly. The ground lab data are biased by the inclusion of areas of dense forbs and shrubs. When observed with the ground spectrometer, they fill the field of view, resulting in very low red reflectance and high infrared reflectance. They also have higher biomass than the surrounding rangeland. These patches are quite small and isolated and do not contribute as strongly to the signal recorded by Landsat, which averages over an 80 x 80 metre area. When the samples containing a high proportion of forbs and shrubs are removed from the analysis, the correlation with biomass becomes more like those obtained with the Landsat data.

This discrepancy illustrates a very important sampling consideration. The sampling with the ground spectroscopy laboratory was designed to obtain information on the spectral reflectance of various rangeland constituents in order to provide greater understanding of the optical behaviour of rangeland. Qualitatively, this has been very successful, as shown by the interpretation guides (Tables 5-7) produced for the different rangeland areas, and their agreement with actual remote sensing imagery. For quantitative work, the only unbiased sampling procedure is random sampling, but the procedure is almost never used because the variability of native rangeland demands a very large number of samples to obtain a reliable estimate of the population mean. As discussed previously, Harlan et al. (1979a) found even 100 samples per rangeland class to be inadequate. Most other work, including our own in 1979 (Thomson et al., 1980) has used "representative" sampling, where the sampling frame is positioned in an area judged to be representative of the surroundings. While this procedure undoubtedly can approach the population mean with fewer samples, there is no protection against bias in the selection of the representative area.

We believe that any study of the relationship between reflectance and biomass designed to give quantitative estimates for operational use (where an unbiased biomass estimate is important) should be set up using random sampling. This will involve a much larger effort than the fifty hours or so per test area per month expended for biomass sampling in this study.

4.2.6.2 Ross Lake: Landsat Results

Figure 11 is the imagery from the July 26, 1980 overpass of the area around Ross Lake, Alberta. The results of the ground measurements can be found on Table 17. This area represents a

transition zone between the Mixed Grass Prairie to the east and the Fescue Grasslands of the Foothills to the west and north. Although the rangelands are quite similar to those found at Stavely, there were no trees and few shrubs, and oatgrass was not prevalent. As well, less productive sites were dominated by species more characteristic of the Mixed Grass Prairie such as needle-and-thread and blue grama grass. Figure 12 shows the location of the sampling transects used in this study.

It should be noted that the highest elevations of the Milk River Ridge are quite pink on the imagery. Increased precipitation with elevation on the ridge has produced broad-leafed forbs and shrubs throughout the grasslands. This more vigorous growth has increased reflectance in the near-infrared which is represented by pink on the image. Fenceline contrasts between rangelands with different cattle utilization which were so evident on imagery from the Mixed Grass Prairie are not as distinct here. For example, adjoining fields at A and B on Figure 12 had significantly different utilization patterns. Cattle on field A concentrated farther west and in the wide coulees characteristic of the area with the result that the upland ranges were in excellent condition. On field B, cattle use was more even over the whole lease for the entire growing season and the ranges during the measurement period were only in fair condition. However, there is very little difference in the signatures of these areas on the Landsat imagery (nor was there on the large-scale false colour infrared photography flown in June and July). This is illustrated by comparing the DCS Landsat imagery with the biomass clipping data collected along the various transects distributed throughout the area.

Transects 5 and 6 are located on upland Fescue Grasslands in excellent condition (Figure 12). Transect 5 was not sampled after June as it was very difficult to reach and provided little additional information. The upland ranges in this area are seldom utilized by cattle as grazing tends to be concentrated in coulees and lowlands. As a result, the brown carryover and litter have built up to considerable depths below the green growth. The total biomass is very high (approximately 5000 kg/ha in July), but the percentage of green grass is relatively low (only about 35% of the total biomass). As well, only a small percentage of the biomass is comprised of broad-leafed plants (approximately 10%). In the Mixed Grass Prairie, this kind of biomass and composition would have appeared dark blue on the imagery and not light blue as it does here. It should also be noted that there is a slightly mottled texture on the imagery for this area, which is associated with the prevalence of small lows in the undulating topography dominated by greener grass and more vigorous broad-leafed plants resulting from the increased moisture.

Transects 1 to 4 (Figure 12) were located in rangelands in fair condition. This area receives heavier cattle use over the whole range and particularly near dams and salt licks (transects 2 and 4). As a result, there is much less rough fescue, a prevalence of broad-leafed plants, and a reduction in the brown carryover and ground litter. This area does not appear appreciably different on the imagery from the excellent condition rangelands. However, the

tone is slightly lighter and there are fewer pink mottles because of the flatter topography and general lack of depressions. An examination of imagery from overpasses earlier and later in the 1980 growing season also did not reveal any significant contrasts.

Table 17 gives the actual biomass and cover measurements for these transects. There are no significant differences among transects 1 to 4. It is immediately apparent that total biomass has been substantially reduced from transects 5 and 6 by heavier grazing (by more than one-half, from 4800 kg/ha to less than 2000). The percentage of green grass is much the same (35 to 40%) although rough fescue has largely been replaced by Idaho fescue, bluegrass, needle-and-thread, and the wheatgrasses. As well, there is less brown material and more broad-leafed plants. In some areas, some of the underlying soils were exposed.

Thus differences between these two areas are significant, particularly in biomass and the ratio by weight of green vegetation to litter plus carryover. However, there is little difference in spectral reflectance between the two leases. This is because both the good and poor areas have approximately the same percentage of ground surface covered by green and brown material. In the poor areas the brown matter, which has a lower percentage of total weight than in the good areas, is distributed horizontally between short tufts of green grass. However, in the excellent areas, the brown matter has a predominantly vertical structure and therefore is less apparent to a nadir-viewing sensor.

It is interesting to note that there was a striking difference between the good and poor areas when observed obliquely by a ground level observer. The poor areas look predominantly green because one does not see the bare patches between the short tufts of green grass, while the high carryover makes the good areas look much browner.

The lack of green, red, and near-infrared spectral differences between the good and poor rangeland areas is apparent in the results presented in the interpretation guide (Table 6) and in the regression analysis (Table 12). As discussed above and in Appendix B, the reason for this is the wide range of green/brown ratio observed in both the good and the poor areas, and the differing geometry which makes the poor areas look approximately as brown as the good areas when viewed from above.

However, Tables 6 and 12 do show a relationship, which improves throughout the growing season, between total biomass and mid-infrared reflectance in bands TM5 and TM6. As mentioned in Section 4.2.3, this encourages us to expect that the thematic mapper will be able to provide images that can be used to evaluate the condition of the Fescue Prairie.

Some simulated thematic mapper test images are discussed in Section 4.3.

4.2.6.3 Stavely

Figure 13 and Table 18 are respectively the July 27, 1980 Landsat DCS image and results of the ground measurements for the Agriculture Canada Research Substation near Stavely. This test location represents the Fescue Grasslands with Thin Black Soils on the more rolling terrain of the Foothills. As well, large stands of trees and shrubs are present within the grasslands. A variety of grazing regimes has led to great differences in the amount and type of grasslands at the station. Oatgrass, brome, and timothy are also prevalent. Thus, this test location provides examples of many conditions found throughout the Foothills grazing lands in a small, easily accessible area. However, it is also very small on a Landsat image. An attempt was made to enlarge the imagery more than normal, but then the image became too blurred to be of much use. Topography and the presence of the trees and shrubs both cause problems in interpretation because they tend to obscure information within the image about the grassland. The steep valley sides appear to have created shadows and information is enhanced for the uplands and almost obscured for the lowlands. Broad-leafed plants such as the aspens, willow, snowberry, and shrubby cinquefoil tend to dominate the imagery. It should be noted, however, that stands of trees and shrubs can be differentiated on the imagery as trees are a much darker red than the shrubs. This may be of value for managers contemplating removal of shrubs to increase the grassland. The transects and pastures at the Stavely Research Substation are shown in Figure 14.

Pasture A has been lightly grazed since the 1940s. On the uplands, the vegetation is dominated by rough fescue and the biomass ranges very high, from 4164 to 4920 kg/ha in July 1980. This biomass was primarily brown carryover and litter (60%) until July when the green vegetation overtopped the brown carryover. Grasses dominate this field (only 10% forbs and shrubs in July) and vegetation covers almost all of the ground surface. Although the lowlands in this field were not sampled, visual inspection revealed that cattle concentrate on these sites as they did at Ross Lake so that vegetation biomass, particularly the brown component, was decreased.

The uplands, which are dominated by rough fescue in good to excellent condition, appear a light bright blue. This is comparable to Ross Lake where the very large amounts of brown carryover and litter dominated the reflectance. Although the green vegetation overtopped this litter later in the growing season, it represented only 35% (in August) of the cover and consequently changes in signature were not evident on the satellite imagery.

It was not possible to clearly identify on the imagery the area sampled in field B, the moderately grazed pasture, because of the predominance of trees and shrubs. This transect had a high biomass dominated by rough fescue and oatgrass with an increase in shrubby cinquefoil (see Table 18). There was more green vegetation than in field A. On the imagery, a slightly greenish tone may be associated with part of this field.

A greenish tone also appears to be associated with field C, which cattle use heavily. The vegetation composition has shifted to dominance by oatgrass and, on some sites, of forbs and shrubs (28 to 46% from June to August). It is interesting to note the disappearance of these broad-leafed plants in this pasture in September. As in fields A and B, the amount of brown plant material is higher than the green vegetation in June and July, but in August it is quite a bit less. It should also be pointed out that the decrease in biomass in August may be associated with a response to the continuance of grazing throughout the entire growing season in this field.

Field D was distinct on August 1979 and August 1980 imagery (appearing an even blue-green). However, even with much lower biomass and a completely different character, it was not easily discernible on the July imagery, although a small strip of bright blue just visible on the photograph may be associated with this field. This was quite surprising as the biomass for every month in the growing season was considerably lower than in the other fields (342 to 880 kg/ha compared with 1500 to 5846 for fields A, B, C, and E) and the vegetation appeared more like that in the Mixed Grass Prairie with a sparse growth of short grasses and broad-leafed plants and soil exposed between the plants. As well, there was little carryover and litter present so that, even in October, this field was visually greener than adjacent pastures in better condition. Thus, we expected that this field would appear light pink on the imagery as did similar ranges at Little Bow. One problem may be that this field was just too small (1/8th the size of field A) to be discriminated completely on the satellite imagery, so that information from adjacent fields contributed to the reflectance patterns. As well, the pasture sloped steeply from the centre to both the east and west and much of the information from the ground surface may have been "contaminated" by illumination effects.

Two transects were located in areas of oatgrass and bromegrass in the eastern part of the research station (field E). These ranges have not been grazed for some time and vegetation biomass is quite high (see Table 18). Again, carryover and litter formed a large part of the biomass, especially in June and July. These areas were also difficult to distinguish on the imagery but appear to be greenish in tone. The slight differences between the appearance of the oatgrass- and bromegrass-dominated areas and the areas dominated by dense rough fescue on the Landsat imagery were also observed in the spectroscopic data. These differences appear to be caused by intrinsic differences in the colours of the vegetation itself.

A distinct fenceline contrast was noted at F on the July 27, 1980 imagery (Figure 13). This range, owned by a neighbouring rancher, had been used heavily by cattle, at least in 1980, and there were marked differences in the vegetation biomass and composition. In particular there was an increase in shrubby cinquefoil compared with the adjacent pasture. Although this pasture can be easily distinguished on the imagery, its green and bright blue tone are puzzling as the vegetation was short and dominated by forbs and shrubs and rough fescue was absent.

4.3 EVALUATION OF SIMULATED THEMATIC MAPPER IMAGERY

Simulated thematic mapper images were created from data acquired with the CCRS Daedalus DS 1260 airborne multispectral scanner on July 22, 1980. Spectral bands 3, 5, 7, 9, and 11 of the multispectral scanner closely approximate thematic mapper bands 1-5 (Zwick et al., 1980). The difficulty of estimating atmospheric and illumination parameters precluded the transformation of the measured radiances into reflectance units. A simple contrast stretch using breakpoints chosen from a display of the histogram of intensities was used to provide good contrast on the simulated thematic mapper imagery.

Figures 15(a), 16(a), and 17(a) were produced as standard colour infrared images by displaying green intensity (TM2) as blue, red intensity (TM3) as green, and near-infrared intensity (TM4) as red. Figures 15(b), 16(b), and 17(b) were produced with red intensity (TM3) displayed as blue, near-infrared intensity (TM4) displayed as green, and mid-infrared intensity (TM5) displayed as red. A discussion of a visual analysis of these images is presented in the next three sections.

4.3.1 Little Bow

It is immediately apparent that contrasts over the range at Little Bow are more easily discernible on Figure 15(a), the band combination available from the present Landsat satellites. One reason for this is the greater contrast between the orange and grey colours on this image than between the greens and browns on the imagery for TM3, 4, and 5. For example, in Figure 15(a), the ranges south and just to the west of Little Bow Reservoir are in poor to fair condition and are quite distinct from the good to excellent ranges to the northwest, which are much darker and greyish. As well, within the good to excellent ranges, the boundaries of the areas that had been cultivated many years ago and that have now returned to native species (A and B in Figure 15(a)) are easily identified. In Figure 15(b), there is very little difference between the ranges in poor and good condition, although the previously cultivated areas are slightly darker in tone. The areas of crested wheatgrass at C and D are distinct and are darker than the best native species.

4.3.2 Ross Lake

Using the Landsat colour infrared imagery, we had difficulty in distinguishing between the upland Fescue Grasslands in excellent condition and the ranges in fair condition. There were, however, marked differences in the type and amount of vegetation in the two areas. On the thematic mapper imagery, a contrast is visible between these ranges, which is more apparent on the TM3, 4 and 5 image (Figure 16(b)). As discussed previously, the uplands (area A) are rarely utilized by cattle and the ranges are in very good condition dominated by rough fescue with approximately 5000 kg/ha in July - much of which is brown carryover and litter. On the ranges in fair condition (area B), the green and brown biomass has been reduced by one-half to one-third, and the composition has changed to less palatable grasses and forbs and shrubs. In Figure 16(a), the ranges

in excellent condition are more orange than those in fair condition, but the blue tones are similar. In Figure 16(b), the ranges in excellent condition (area A) are greener and more even in texture while the fair range (area B) appears a tan colour with mottles of olive green (probably associated with the myriad lows in the area supporting denser vegetation). The yellowish green colour associated with the planted forage species, bromegrass and sainfoin (area C on Figure 16(b)) is also of interest. These areas were visible on Figure 16(a) as well, but the orange colour was not different from other range areas associated with forbs and shrubs and cultivated crops.

4.3.3 Stavely

Problems occurred in relating Landsat imagery and large-scale false colour infrared photography to actual range condition at Stavely where the excellent rough fescue stands appeared little different on the imagery from the very poor pasture, which had much less plant biomass, many shrubs and forbs, and some areas of exposed soil. This is also evident on the thematic mapper normal colour infrared imagery (Figure 17(a)). The areas of range in excellent condition (area A on Figure 14) and the heavily grazed pastures (at D and F) are both medium blue whereas other ranges in good or fair condition have an orange cast. But note that on the TM3, 4 and 5 image (Figure 17(b)), the pastures in very poor and excellent condition can now be separated. Field D, parts of field C, and the large pasture at F (Figure 14), which were both very heavily grazed, are tan (similar to the poorer condition ranges on the Ross Lake image) while the less used uplands in good to excellent condition are green. It is also interesting to note that fenceline contrasts which were visible on the ground but not on other imagery are now apparent (for example at G, H and I on Figure 17(b)).

Apparently the TM combination 3, 4 and 5 may be potentially more useful in the Fescue Grasslands than 2, 3 and 4 and the corresponding MSS4, 5 and 7. In the Mixed Grass Prairie however, the contrasts in range condition were more visible on TM2, 3 and 4, corresponding to the MSS4, 5 and 7 combination.

4.4 CONCLUSIONS: RESEARCH AND DEVELOPMENT COMPONENT

1. Analysis of the CCRS V-IR Spectroscopy Laboratory data did not establish a strong relationship between the reflectance factor in thematic mapper bands TM2 through TM6 and the biomass of grass, forbs, grass plus forbs, litter, carryover, litter plus carryover, or total biomass in the Mixed Grass and Fescue Prairies of southern Alberta. Linear regression analysis with each of the above biomass types as the independent variable and thematic mapper bands TM3 through TM6 as the dependent variable resulted in coefficients of determination of at most 0.7 and typically 0.4 or less. The reason for this has been traced to the complexity of the rangeland, with grasses, forbs, litter, and carryover occurring in widely varying proportions each contributing to the reflectance factor in a different way.

A nonlinear multivariate model might lead to better results but far more samples, obtained in a truly random fashion, would be necessary to establish such a model.

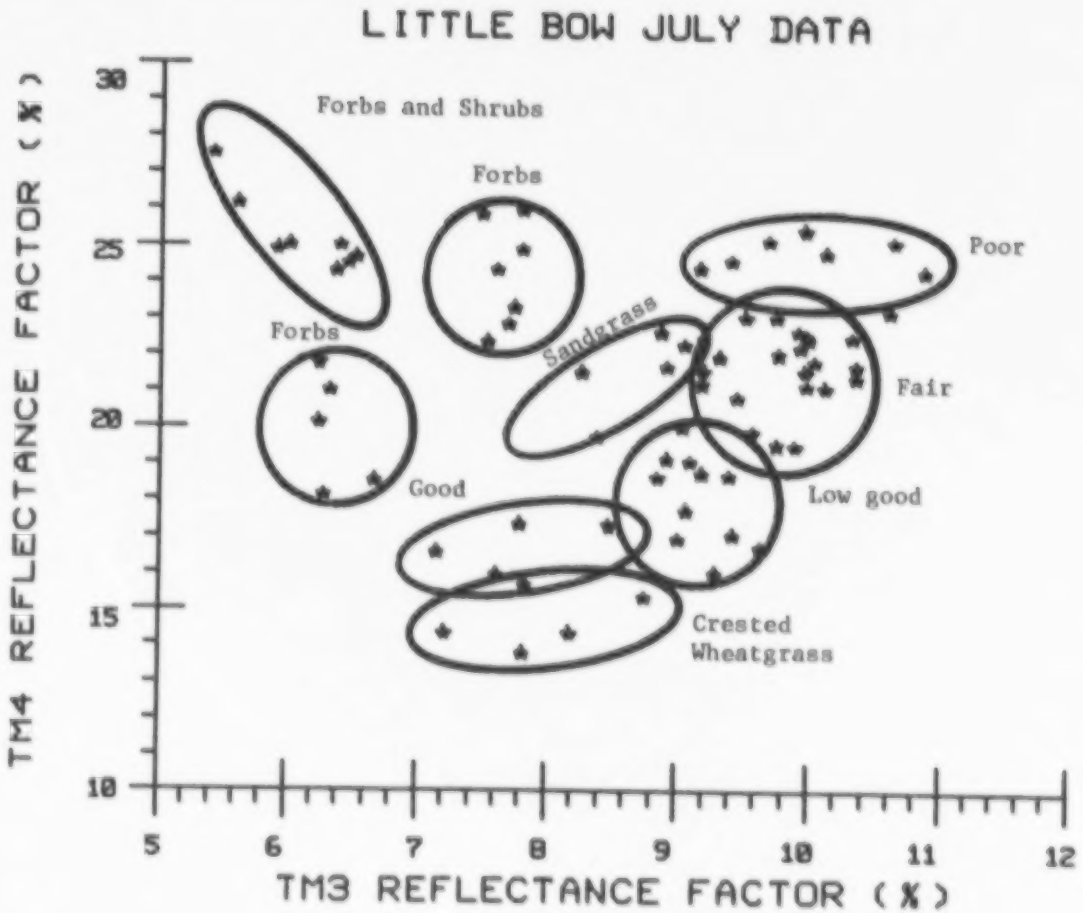
2. A comparison between biomass values obtained from ground transects and Landsat digital data showed relationships that substantiated and complemented those obtained with the ground spectroscopy laboratory. Once again, however, the coefficients of determination thus obtained were too low to encourage the pursuit of a method for making quantitative biomass estimates in an operational setting.

3. The quantitative and qualitative ground spectroscopy laboratory results have led to a much greater understanding of the way in which the reflectance factor of rangeland in the visible, near-infrared, and mid-infrared spectral regions is related to the nature of various rangeland areas. In the Mixed Grass Prairie, the reflectance factor throughout the visible, near-infrared, and mid-infrared region decreases with increasing biomass and range condition. The only exception occurs in areas with dense green vegetation and very little carryover where the near-infrared spectral reflectance increases with increasing biomass. These areas are generally too small to allow this effect to dominate on the scale of a Landsat MSS pixel.

In the Fescue Prairie, the reflectance factor in the visual range decreases as green biomass (grass, forbs and shrubs) increases, but increases as brown biomass (litter and carryover) increases. The reflectance factor in the near-infrared increases as green biomass increases, but decreases as brown biomass increases. These competing effects, coupled with the wide range of the green to brown ratio in both good and poor areas, render visible and near-infrared imagery quite ineffective in discriminating all but the most extreme range condition classes. The situation is rather more hopeful in the mid-infrared (1.5 to 2.5 micrometre wavelength) where the reflectance factor decreases as both green and brown biomass increases. Both qualitative and quantitative analyses of the data indicate that imagery incorporating this wavelength region should be capable of discriminating up to three or four range condition classes with the discrimination improving with increasing senescence. Simulated thematic mapper imagery has been evaluated and confirms the value of this spectral region.

4. The understanding of rangeland reflectance properties obtained with the ground spectroscopy laboratory has been used to create an interpretation guide for use with current and future colour composite imagery of the Mixed Grass and Fescue prairies. The predictions of this guide have been confirmed for areas where suitable imagery was available.

5. Visible and near-infrared colour composite imagery of the Fescue Prairie can be used to identify large areas of forbs and/or shrubs and areas of dense green grass such as found in coulees.



Range Class	Dry Biomass (Kg/ha) Total	Grass	Litter
Good	2300	1700	500
Low good	1200	1000	200
Fair	750	500	100
Poor	600	400	100

FIGURE 7: Two band scatter diagram of reflectance factor measurements of various biophysical range classes at Little Bow, July 1980.

TM4 (0.76 - 0.90 micrometres) vs.
TM3 (0.63 - 0.69 micrometres)

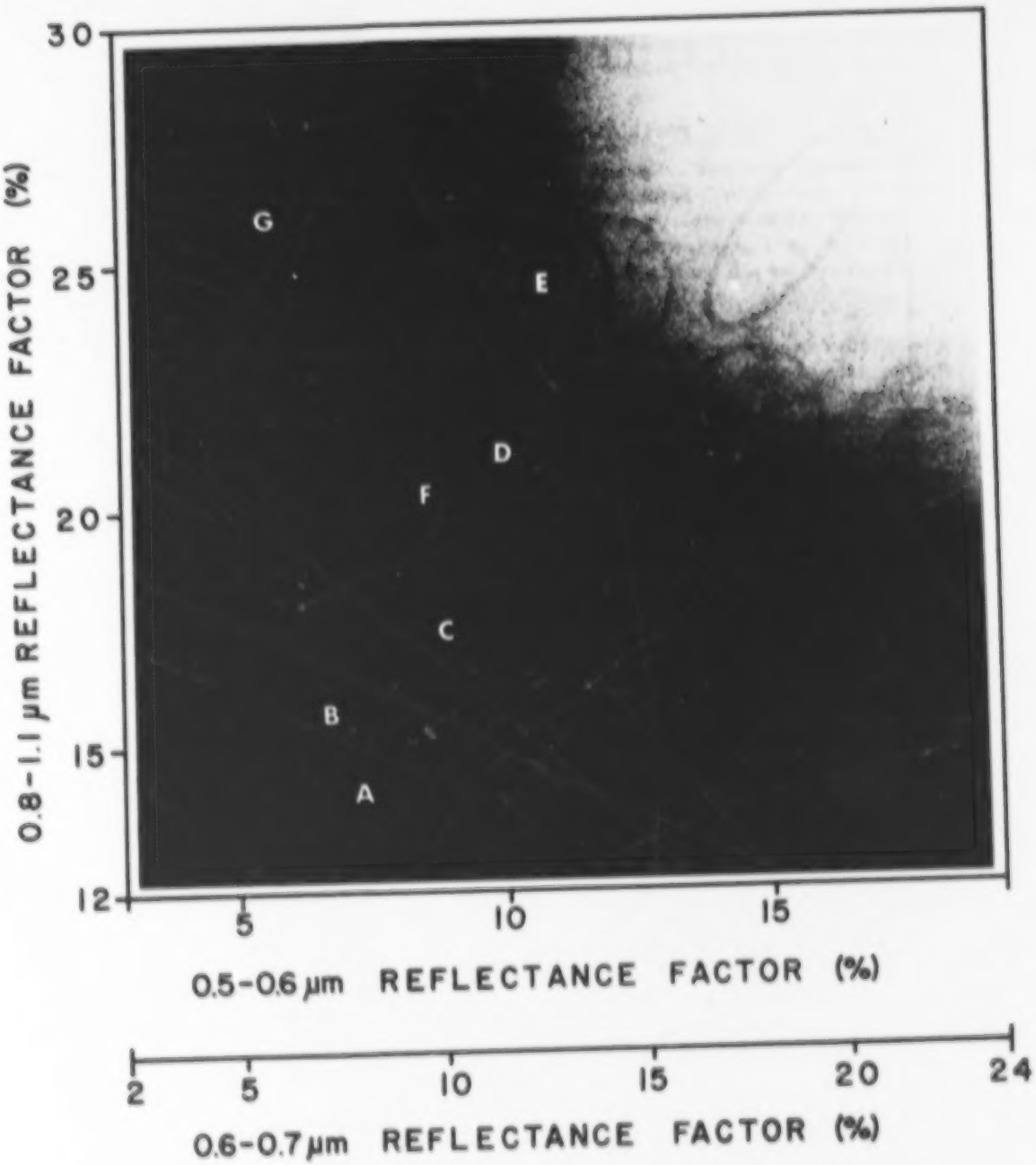


FIGURE 8: Colour prediction diagram showing the locations of some of the biophysical range classes identified in Figure 7.

A = crested wheatgrass, B = good, C = low good, D = fair, E = poor, F = sandgrass, G = forbs and shrubs.

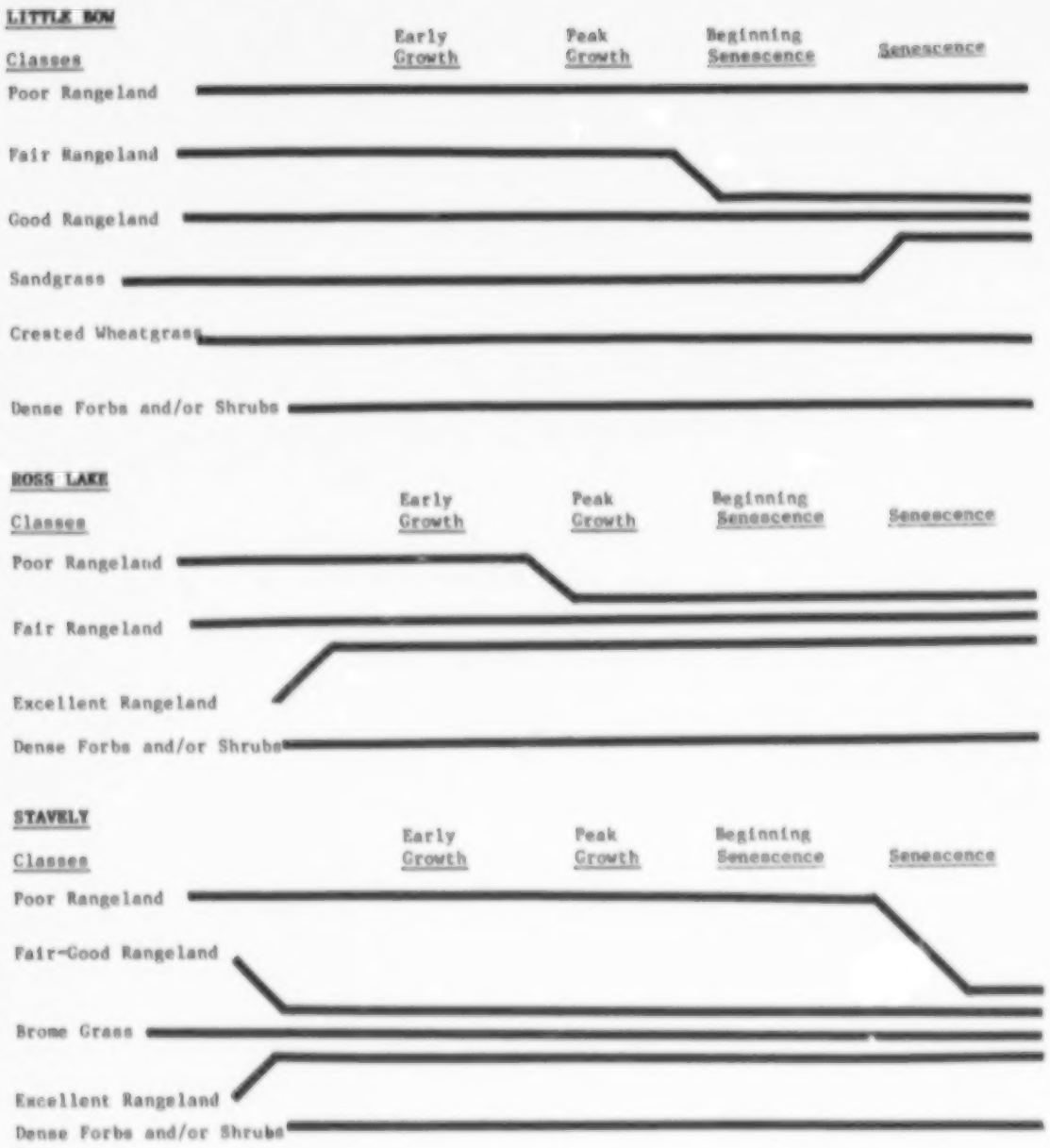


FIGURE 9: Schematic representation of range condition class separability using imagery created from data in the green, red, and near-infrared spectral regions. The diagram indicates separated classes which are far from their neighbours, with solid lines and confused classes which are near their neighbours with solid lines. The estimated class separability is based on a subjective assessment of overlap ground reflectance data points in two dimensional scatter plots like those shown in Figure 7.

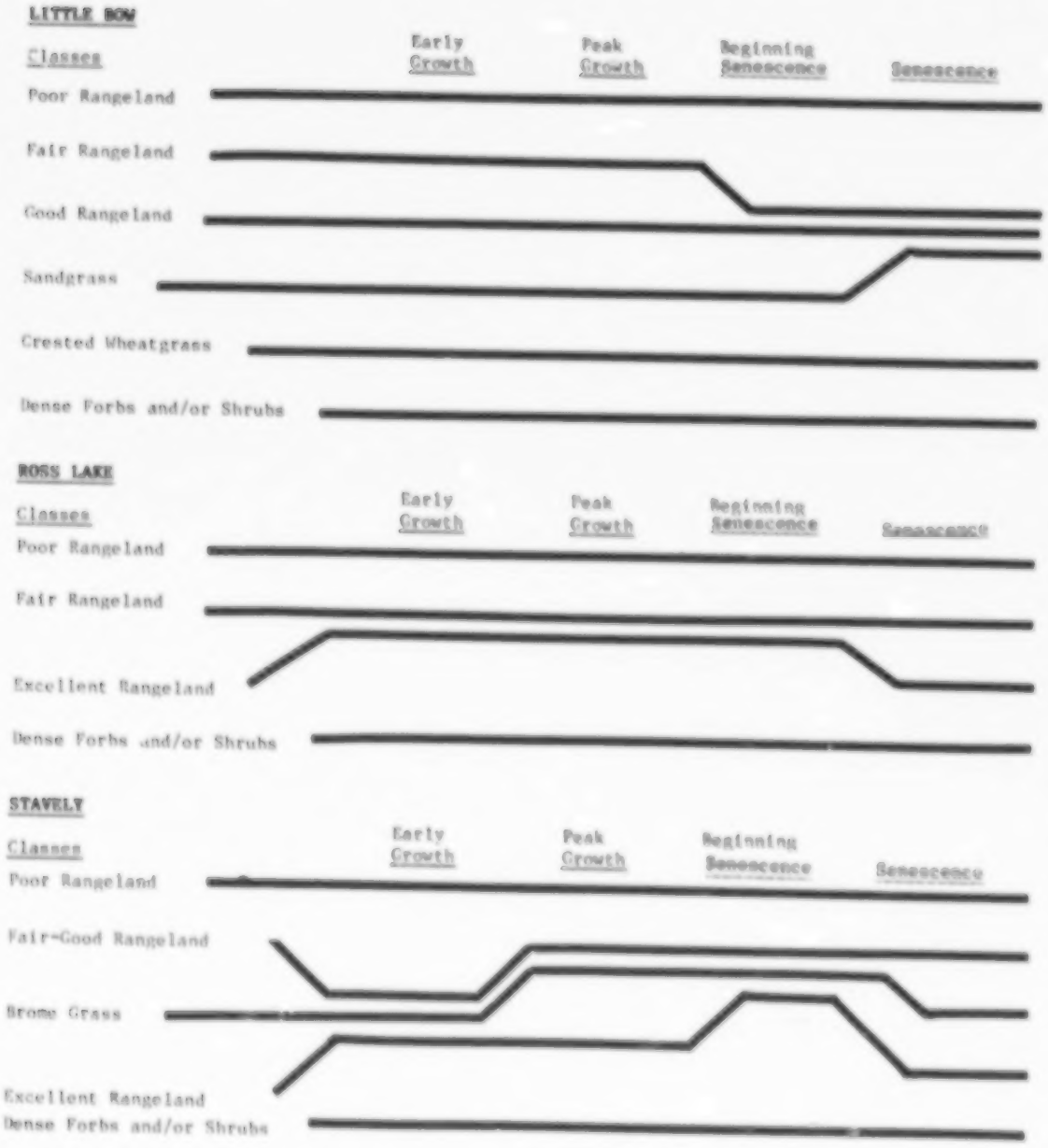


FIGURE 10: This is the same representation used in Figure 9, but using data in the red, near-infrared, and mid-infrared spectral regions. Note how the separability is better in the fescue prairie (Ross Lake and Stavely) at the senescence stage than with the green, red, and near-infrared data used in Figure 9.

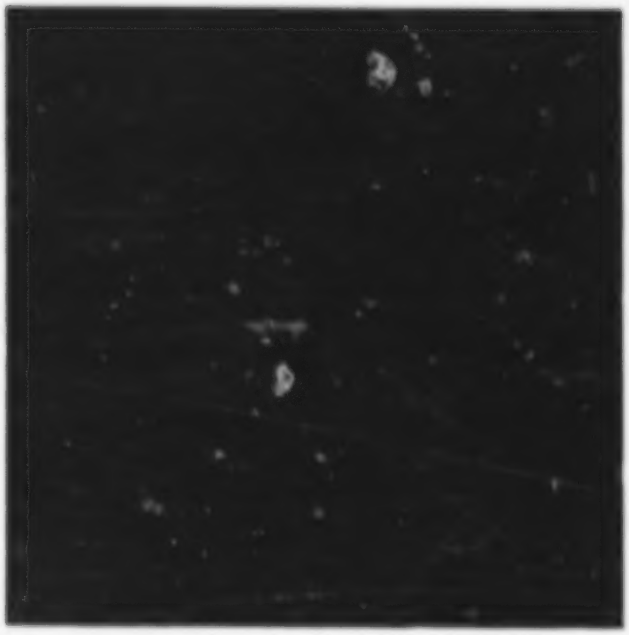


FIGURE 11: Digitally contrast stretched image of the Ross Lake Grazing Association and its surroundings, July 26, 1980.

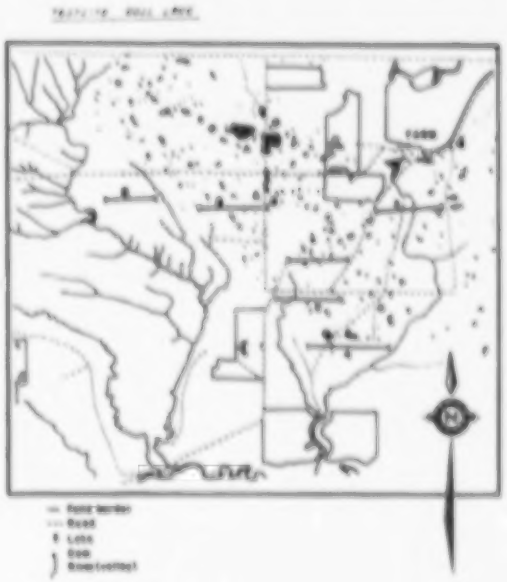


FIGURE 12: Key to Figure 11.

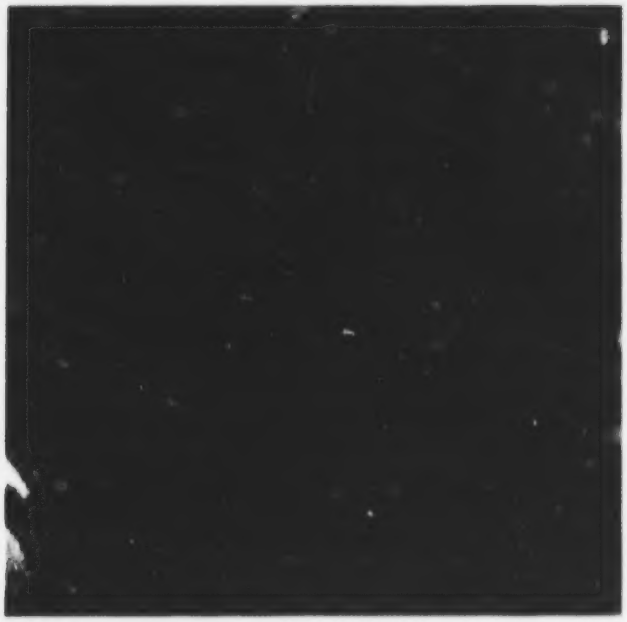


FIGURE 13: Digitally contrast stretched image of the Stavely Research Substation and its surroundings, July 27, 1980.

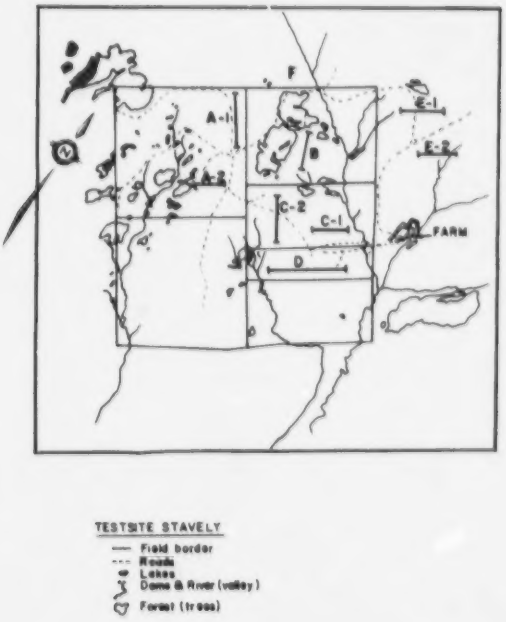
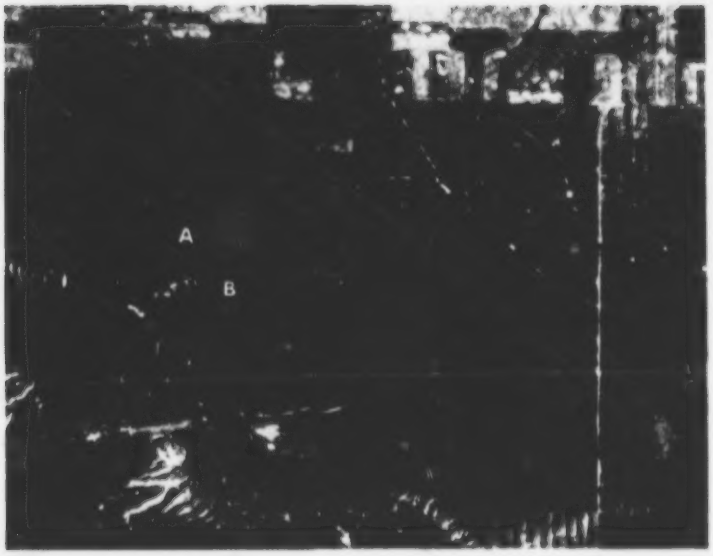


FIGURE 14: Key to Figure 13.



15(a)

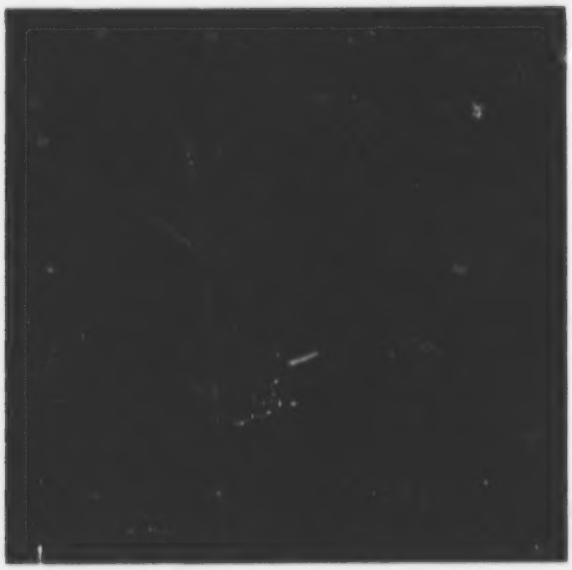
FIGURE 15: Thematic Mapper simulation from July 22, 1980. Airborne multispectral scanner data, Little Bow test area.

(a) Blue = TM2, green = TM3, red = TM4. See text for further explanation.

(b) Blue = TM3, green = TM4, red = TM5.

Areas A and B are areas which have returned to native rangeland after previous cultivation.

15(b)



16(a)

FIGURE 16: Thematic Mapper simulation from July 22, 1980 airborne multispectral scanner data, Ross Lake test area.

(a) Blue = TM2, green = TM3, red = TM4.

(b) Blue = TM3, green = TM4, red = TM5.

Area A is a very lightly grazed upland area while area B is heavily grazed with less total biomass and far less carryover than area A. Area C is a pasture planted to bromegrass and sainfoin.

16(b)

17(a)

FIGURE 17: Thematic Mapper simulation from July 22, 1980 airborne multispectral scanner data, Stavely test area.

(a) Blue = TM2, green = TM3, red = TM4.

(b) Blue = TM3, green = TM4, red = TM5.

Pastures A through F are indicated on the key for Stavely, Figure 14. The green squares in Figures 17(a) and (b) correspond to the test area boundary in Figure 14. Fenceline contrasts at G, H, and I are more readily apparent in the new colour combination in Figure 17(b) than in the presently available colour composite shown in Figure 17(a).

17(b)

5. CONCLUSIONS

A digitally contrast stretched Landsat image product has been eloped that provides useful information on range condition within the Mixed Grass Prairie. This product has been evaluated by field staff of the Lethbridge and Medicine Hat offices of the Public Lands Division, Alberta Energy and Natural Resources. They found that the tones on the images of regions within the Mixed Grass Prairie could be related to range condition. In general, it was found that good to excellent areas associated with abundant grass and large amounts of carryover and litter appeared darker on the imagery than poorer areas with little carryover. This same product did not determine range condition as reliably within the Rough Fescue Prairie.

Analysis of the Spectroscopy Laboratory data did not establish a strong relationship between biomass and spectral reflectances in both the Mixed Grass and Rough Fescue prairies of southern Alberta. However, these data did show the qualitative relationship between spectral reflectances and range condition. Based upon these data, an interpretation guide for use with current colour composite imagery of the Mixed Grass Prairie was developed.

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7. REFERENCES

Ahern, F.J., R.J. Brown, D.G. Goodenough, K.P.B. Thomson, 1980. "A Simulation of Thematic Mapper Performance in an Agricultural Application", Proc. of the Sixth Can. Symp. on Rem. Sens., Halifax, Nova Scotia, pp. 585-596.

Ahern, F.J., P.M. Teillet, D.G. Goodenough, 1979. "Transformation of Atmospheric and Solar Illumination Conditions on the CCRS Image Analysis System", Proc. of the 1979 Mach. Proc. of Rem. Sens. Data Symp., West Lafayette, Indiana, pp. 34-52.

American Society of Photogrammetry, 1975. Manual of Remote Sensing, Falls Church, Va. Volumes I and II, 2144 pp.

Brown, R.J., F.J. Ahern, 1980. "The Field Spectral Measurement Program of the Canada Centre for Remote Sensing", Can. J. of Rem. Sens. 6, pp. 26-37.

Brown, R.J., F.J. Ahern, R.A. Ryerson, K.P.B. Thomson, D.G. Goodenough, J.A. McCormick, P.M. Teillet, 1980. "Rapeseed: Guidelines for Operational Monitoring", Proc. of the Sixth Can. Symp. on Rem. Sens., Halifax, Nova Scotia, pp. 321-330.

Bunting, B.T., 1965. The Geography of Soil, Aldine Publishing Co., Chicago, 213 pp.

Canadian Soil Survey Committee, 1978. The Canadian System of Soil Classification, Research Branch, Agriculture Canada Publication 1646, 164 pp.

Carneggie, D.M., S.D. Delgloria, R.N. Colwell, 1974. "Usefulness of ERTS-1 and Supporting Aircraft Data for Monitoring Plant Development and Range Conditions in California's Annual Grassland", Final Report No. 53500-CT3-266(N) Remote Sensing Research Program, School of Forestry and Conservation, University of California, Berkeley.

Carneggie, D.M., K.G. Bonner, J.A. Sturdevant, 1979. "A Selected Bibliography: Application of Remote Sensing for Range Management", USDI, Geol. Surv., EROS Data Center, Sioux Falls, S.D.

Coupland, R.T., 1958. "The Effects of Fluctuations in Weather Upon the Grasslands of the Great Plains", Bot. Rev. 24(5), pp. 273-317.

Coupland, R.T., 1961. "Reconsideration of Grassland Classification for the Northern Great Plains of North America", J. Ecol. 49, pp. 135-167.

Deering, D.W., J.W. Rouse, R.H. Haas, J.A. Schell, 1975. "Measuring Forage Production of Grazing Units from Landsat MSS Data", Proc. of the Tenth Intern. Symp. on Rem. Sens. of Env., Ann Arbor, Michigan, pp. 1169-1178.

Deering, D.W., R.H. Haas, 1977. "Using Landsat Digital Data for Estimating Green Biomass", Symposium on Rangeland Remote Sensing, 30th Annual Meeting of the Society for Range Management, Portland, Oregon, 33 pp.

Dormaar, J.F., A. Johnston, S. Smoliak, 1977. "Seasonal Variations in Chemical Characteristics of Soil Organic Matter of Grazed and Ungrazed Mixed Prairie and Fescue Grassland", J. Range Manage. 30(3), pp. 195-198.

Driscoll, R.S., 1974. "Use of Remote Sensing in Range and Forest Management", Proc. of the Great Plains Agric. Counc., pp. 111-133.

Gates, D.M., 1968. "Energy Exchange Between Organism and Environment", in William P. Lowery (Ed.), Biometeorology. Oregon State University Press, Corvallis, Oregon, 542 p.

George, T.H., W.J. Stringer, J.N. Baldridge, 1977. "Reindeer Range Inventory in Western Alaska from Computer-Aided Digital Classification of Landsat Data", Proceedings of the 11th Intern. Symp. on Rem. Sens. of Env., Ann Arbor, Michigan, pp. 671-681.

Goodenough, D.G., 1979. "The Image Analysis System (CIAS) at the Canada Centre for Remote Sensing", Can. J. of Rem. Sens., 5, pp. 3-17.

Graf, R.F., 1973. "Soil Moisture Tester", Mechanics Illustrated, May 1973, pp. 62-63.

Harlan, J.C., D.W. Deering, R.H. Haas, W.E. Boyd, 1979a. "Determination of Range Biomass Using Landsat", Thirteenth Intern. Symp. on Rem. Sens. of Env., Ann Arbor, Michigan, pp. 659-673.

Harlan, J.C., W.E. Boyd, C. Clark, S. Clarke, O.C. Jenkins, 1979b. "Rangeland Resource Evaluation from Landsat", Final Report NASA Contract No. NAS9-15465, Texas A & M University.

Intera, 1977. "Rangeland Remote Sensing Pilot Project", DSS Contract Number OSZ 76-00183, Intera Environmental Consultants Limited, Calgary, Alberta, 183 pp..

Intera, 1979. "Remote Sensing for Estimation of Rangeland Productivity and Condition at Onefour Research Substation, Alberta", Report submitted to Canada Agriculture, Lethbridge Research Station, Intera Environmental Consultants Limited, Calgary, Alberta, 51 pp.

Jaques, D., J. Cihlar, 1979. "Estimation of Vegetation Biomass in Bunchgrass Rangelands of Alberta Using Landsat Imagery", Remote Sensing of Earth Resources Volume VII, University of Tennessee Space Institute, Tullahoma, Tennessee. Edited by F. Shahrokhi (in press).

Johnston, A., J.F. Dormaar, 1970. "Observations on Vanthonia parryi", Can. J. Pl. Sci., 50, pp. 115-117.

Johnston, A., S. Smoliak, L.M. Forbes, J.A. Campbell, 1967. "Alberta Range Management Guide", Alberta Department of Agriculture, Lands and Forests, Pub. No. 134/14, 32 pp.

Maxwell, E.L., 1975. "Application of ERTS to Rangeland Management", Proceedings of the 4th Annual Remote Sensing of Earth Resources Conference, University of Tennessee, Tullahoma, Tennessee, pp. 105-135.

Maxwell, E.L., 1976. "Multivariate Systems Analysis of Multispectral Imagery", Photo. Eng. and Rem. Sens., 42, pp. 1173-1186.

Moss, E.J., J.A. Campbell, 1947. "The Fescue Grassland of Alberta", Can. J. Res. C. 25, pp. 209-227.

Olsen, C.E., Jr., 1967. "Optical Sensing of the Moisture Content in Fine Forest Fuels", IST Report 8036-1-F, Univ. Michigan, Ann Arbor, 21 pp.

Pearce, C.M., 1980. "An Evaluation of Satellite-Generated Information for Inclusion in Rangeland Monitoring Programs in Alberta", M.Sc. Thesis, Dept. of Geography, University of Calgary, Alberta, 206 pp.

Rouse, J.W., R.H. Haas, J.A. Schell, D.W. Deering, 1973. "Monitoring Vegetation Systems in the Great Plains with ERTS", Third Earth Resources Technology Satellite-1 Symposium, University of Tennessee, Tullahoma, Tennessee, pp. 309-317.

Salmon-Drexler, B.C., 1977. "Reducing Landsat Data to Parameters with Physical Significance and Signature Extension: A View of Landsat Capabilities", Proceedings of the Eleventh Intern. Symp. on Rem. Sens. of Env., Ann Arbor, Michigan, pp. 1289-1299.

Sinclair, T.R., R.M. Hoffer, M.M. Schreiber, 1971. "Reflectance and Internal Structure of Leaves from Several Crops During a Growing Season", Agron. J. 63, pp. 864-868.

Smoliak, S., R.A. Wroe, A. Johnston, M.G. Turnbull, 1976a. "Guide to Range Condition and Stocking Rates for Alberta", Alberta Energy and Natural Resources, 26 pp.

Smoliak, S, A. Johnston, M.R. Kilcher, R.W. Lodge, 1976b. "Management of Prairie Rangeland, Agriculture Canada, Publication No. 1589, 30 pp.

Staenz, K., F.J. Ahern, R.J. Brown, 1980. "Evaluation of Thematic Mapper Bands: A First Step in Feature Selection", Proceedings of the Sixth Can. Symp. on Rem. Sens., Halifax, Nova Scotia, pp. 625-634.

Staenz, K., F.J. Ahern, R.J. Brown, 1981. "The Influence of Illumination and Viewing Geometry on the Reflectance Factor of Agricultural Targets", Proceedings of the Fifteenth Intern. Symp. on Rem. Sens. of Env., Ann Arbor, Michigan (in press).

Suits, G.H., 1972. "The Calculation of the Directional Reflectance of a Vegetative Canopy", Rem. Sens. of Env., 2, pp. 183-192.

Thomson, K.P.B., F.J. Ahern, R.J. Brown, K. Staenz, D.H. McCartney, J. Waddington, 1980. "Spectral Measurements of Rangeland", Proc. Sixth Can. Symp. on Rem. Sens., Halifax, Nova Scotia, pp. 377-386.

Totterdell, C.J., A.B. Rains, 1973. "Plant Reflectance and Colour Infrared Photography", J. Appl. Ecol. 10, pp. 401-407.

Tucker, C.J., 1977a. "Asymptotic Nature of Grass Canopy Spectral Reflectance", App. Opt., 16, pp. 1151-1156.

Tucker, C.J., 1977b. "Spectral Estimation of Grass Canopy Variables", Rem. Sens. of Env., 6, pp. 11-26.

Tucker, C.J., 1978a. "Post Senescent Grass Canopy Remote Sensing", Rem. Sens. of Env., 7, pp. 203-210.

Tucker, C.J., 1978b. "A Comparison of Satellite Sensor Bands for Vegetation Monitoring", Photo. Eng. and Rem. Sens., 44, pp. 1369-1380.

Watson, E.K., 1977. "A Remote Sensing Based Multilevel Rangeland Classification for the Lac-du-Bois Rangelands", Kamloops, British Columbia, Masters Thesis, Faculty of Forestry, University of British Columbia, 85 pp.

Wyatt, F.A., J.D. Newton, 1925. "Soil Survey of the MacLeod Sheet", University of Alberta, Bulletin No. 11.

Zwick, H.H., W.D. McColl, H.R. Edel, 1980. "The CCRS DS 1260 Airborne Multispectral Scanner (MSS)", Proceedings of the Sixth Can. Symp. on Rem. Sens., Halifax, Nova Scotia, pp. 643-648.

APPENDIX A

A GLOSSARY OF TERMS USED IN RANGE MANAGEMENT

Compiled and edited by

RANGE TERM GLOSSARY COMMITTEE

M.M. Kothmann, Chairman

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ALLOWABLE USE. (1) The degree of use estimated to be proper until proper use is known. Thirty to fifty percent of the annual growth by weight is often used as a rule of thumb on ranges in good or excellent condition. (2) The amount of forage planned to be used in order to accelerate range improvement.

ANIMAL-DAY. One day's tenure upon range by one animal. Not synonymous with animal-unit day.

ANIMAL-MONTH. A month's tenure upon range by one animal. Not synonymous with animal-unit month.

ANIMAL-UNIT. Considered to be one mature (450 kg) cow or the equivalent based upon average daily forage consumption of 11.7 kg dry matter per day. Abbr. A.U. cf. animal-unit conversion factor.

ANIMAL-UNIT CONVERSION FACTOR. A numerical figure expressing the forage requirements of a particular kind or class of animal relative to the requirement for an animal-unit. A conversion factor is satisfactory with respect to the amount of forage required to maintain an animal, but may not be applicable in determining stocking rates for range use for particular kinds or classes of animals because of different grazing preferences.

ANIMAL-UNIT MONTH. (1) The amount of feed or forage required by an animal-unit for one month. (2) Tenure of one animal-unit for period of one month. Not synonymous with animal-month. Abbr. A.U.M.

A.U. Abbreviation for animal-unit.
A.U.M. Abbreviation for animal-unit month.

BROWSE. (n) That part of leaf and twig growth of shrubs, woody vines and trees available for animal consumption. (v) To consume browse. cf. graze.

BROWSE LINE. A well-defined height to which browse has been removed by animals. cf. highlighting.

BRUSH. A growth of shrubs or small trees usually undesirable for livestock or timber management. It may sometimes be of value for browse and for watershed protection.

CARRYING CAPACITY. The maximum stocking rate possible without inducing damage to vegetation or related resources. It may vary from year to year on the same area due to fluctuating forage production. Syn. grazing capacity.

CLASS OF ANIMAL. Age and/or sex-group of a kind of animal. Example: cow, calf, yearling, ewe, doe, fawn.

CLASS OF LIVESTOCK. Age and/or sex-group of a kind of livestock. cf. class of animal.

CLIMAX. The highest ecological development of a plant community capable of perpetuation under the prevailing climatic and edaphic conditions.

COMMON USE. The use of a range by more than one kind of grazing animal either at the same time or at different times within the same growing season.

CONTINUOUS GRAZING. The grazing of a specific unit by livestock throughout a year or for that part of the year during which grazing is feasible. The term is not necessarily synonymous with yearlong grazing.

DECREASER. Plant species of the original or climax vegetation that will decrease in relative amount with continued overuse.

DEFERMENT. Delay or discontinuance of livestock grazing on an area for an adequate period of time to provide for plant reproduction, establishment of new plants, or restoration of vigor of existing plants. cf. deferred grazing.

DEFERRED GRAZING. The use of deferment in grazing management of a management unit, but not in a systematic rotation including other units. cf. grazing system.

DEFERRED ROTATION. Any grazing system having a stocking density index 1 and 2, which provides for a systematic rotation of the deferment among pastures.

FORAGE. (n) All browse and herbaceous foods that are available to grazing animals. It may be grazed or harvested for feeding. cf. range forage. (v) Act of consuming forage. Syn. graze.

FORAGE PRODUCTION. The weight of forage that is produced within a designated period of time on a given area. The weight may be expressed as either green, air-dry or oven-dry. The term may also be modified as to time of production such as annual, current year's or seasonal forage production.

FREQUENCY. A quantitative expression of the presence or absence of individuals of a species in a population; i.e., the ratio between the number of sample units that contain a species and the total number of sample units.

GRAZE. (1) (vi) The consumption of standing forage by livestock or wildlife. (2) (vt) To put livestock to feed on standing forage.

GRAZING. (n) Forage available for grazing. (vt) To graze.

GRAZING CAPACITY. Syn. carrying capacity.

GRAZING MANAGEMENT. The manipulation of livestock grazing to accomplish a desired result.

GRAZING MANAGEMENT PLAN. A program of action designed to secure the best practicable use of the forage resources.

GRAZING PERIOD. The length of time that livestock are grazed on a specific area.

GRAZING PREFERENCE. (1) Selection of certain plants over others by grazing animals. (2) In the administration of public lands, a basis upon which permits and licences are issued for grazing use.

GRAZING SURVEY. The systematic collection of data pertaining to forage resources and other information pertinent to range management. May be either extensive or intensive grazing survey.

GRAZING SYSTEM. A specialization of grazing management which defines systematically recurring periods of grazing and deferment for two or more pastures or management units. Descriptive common names such as "Merrill", "Hormay", "South African switchback", etc., may be used. However, the first usage of a grazing system name in a publication should be followed by a description using a standard format. This format shall consist of a numerical description in the following prescribed order: (the number of pastures (or units)-number of herds: length of grazing periods: length of deferment periods for any given unit in the system followed by an abbreviation of the unit of time used). cf. deferred grazing and deferred rotation grazing.

Examples:

1. Merrill system (4-3;12:4 mo.) is a grazing system with 4 pastures, 3 herds of livestock, a 12 month grazing period and a 4 month deferment period.

2. South African switchback (2-1;3:3,6:3,3: 6 mo.) is a grazing system with 2 pastures, 1 herd, and a grazing cycle of 3 months grazing, 3 months.

INCREASER. Plant species of the original vegetation that increase in relative amount, at least for a time, under overuse.

INDICATOR SPECIES. (1) Species that indicate the presence of certain environmental conditions, serial stages or previous treatment. (2) One or more plant species selected to indicate a certain level of grazing use.

MANAGEMENT PLAN. A program of action designed to reach a given set of objectives. cf. grazing management plan.

MULTIPLE USE. Harmonious use of range for more than one purpose; i.e., grazing of livestock, wildlife production, recreation, watershed and timber production. Not necessarily the combination of uses that will yield the highest economic return or greatest unit output. Syn. multiple land use.

PRESCRIBED BURNING. The use of fire as a management tool under specified conditions for burning a predetermined area.

PRIMARY RANGE. Areas that animals prefer to use when management is limited. Primary range will be overused before secondary range is fully used when animals are allowed to shift for themselves.

PROPER GRAZING. The act of continuously obtaining proper use.

PROPER STOCKING. Placing a number of animals on a given area that will result in proper use at the end of the planned grazing period. Continued proper stocking will lead to proper grazing.

PROPER USE. A degree and time of use of current year's growth which, if continued, will either maintain or improve the range condition consistent with conservation of other natural resources. Syn. proper utilization.

RANGE. Embraces rangelands and also many forest lands that support an understory or periodic cover of herbaceous or shrubby vegetation amenable to certain range management principles or practices. Syn. veld.

RANGE CONDITION. The current productivity of a range relative to what that range is naturally capable of producing.

RANGE CONDITION CLASS. One of a series of arbitrary categories used to classify range condition and usually expressed as either excellent, good, fair or poor.

RANGE CONDITION TREND. The direction of change in range condition. Syn. range trend and trend in range condition.

RANGE FORAGE. Forage produced on range. cf. forage.

RANGE IMPROVEMENT. (1) Any structure or excavation to facilitate management of range or livestock. (2) Any practice designed to improve range condition or facilitate more efficient utilization of the range. (3) An increase in the grazing capacity of range, i.e., improvement in range condition.

RANGE INVENTORY. An itemized list of resources of a management area such as range sites, range condition classes, range condition trends, range use, estimated proper stocking rates, physical developments and natural conditions such as water, barriers, etc.

RANGELAND. Land on which the native vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs or shrubs suitable for grazing or browsing use. Includes lands revegetated naturally or artificially to provide a forage cover that is managed like native vegetation. Rangelands include natural grasslands, savannahs, shrublands, most deserts, tundra, alpine communities, coastal marshes and wet meadows. cf. range.

RANGE MANAGEMENT. A distinct discipline founded on ecological principles and dealing with the husbandry of rangelands and range resources.

RANGE PLAN. See Management Plan.

RANGE READINESS. The defined stage of plant growth at which grazing may begin under a specific management plan without permanent damage to vegetation or soil. Usually applied to seasonal range.

RANGE SCIENCE. The organized body of knowledge upon which the practice of range management is based.

RANGE SITE. A distinctive kind of rangeland, which in the absence of abnormal disturbance and physical site deterioration, has the potential to support a native plant community typified by an association of species different from that of other sites. This differentiation is based upon significant differences.

REST PERIOD. A period of deferment included as part of a grazing system.

REST-ROTATION. See Grazing System.

ROTATION GRAZING. System of pasture utilization embracing short periods of heavy stocking followed by periods of rest for herbage recovery during the same season. Generally used on tame pasture or cropland pasture.

SACRIFICE AREA. A portion of the range, irrespective of site, that is intentionally overgrazed to obtain efficient overall use of the management area.

SACRIFICE SITE. A range site which is intentionally overgrazed to obtain efficient overall use of the management area.

SEASONAL GRAZING. Grazing restricted to a specific season. cf. grazing system.

SEASONAL USE. (1) Synonymous with seasonal grazing. (2) Seasonal preference of certain plant species by animals.

SPECIES COMPOSITION. The proportions of various plant species in relation to the total on a given area. It may be expressed in terms of cover, density, weight, etc.

STOCKING DENSITY. The relationship between number of animals and area of land at any instant of time. It may be expressed as animal-units per acre, animal-units per section, or A.U.M./ac. cf. stocking density index, stocking rate, stocking pressure.

STOCKING DENSITY INDEX. The reciprocal of the fraction: land available to the animals at any one time/land available to the animals for the entire grazable stocking period.

STOCKING PLAN. The number and kind of livestock assigned to one or more given management areas or units for a specified period.

STOCKING PRESSURE. The weight of forage that the operator has allowed per animal-unit for a relatively short grazing period of specified length. Expressed as wt. forage/A.U. cf. stocking rate, stocking density.

STOCKING RATE. The area of land that the operator has allotted to each animal-unit for the entire grazable period of the year. May be expressed as a ratio in various forms such as: A.U./Section; ac./A.U.; or ac./A.U.M. cf. stocking density, stocking pressure.

APPENDIX B

B.1 FACTORS INFLUENCING THE REFLECTANCE OF RANGELAND

We have achieved a considerable understanding of the reflectance behaviour of rangeland in this study. Although the results are derived from a study of the Mixed Grass and Fescue prairies of Alberta, we believe they are relevant to other types of rangeland. In this appendix, we will start with general principles that we believe hold in all cases and then apply rules of thumb which usually hold true, to specific examples demonstrating how these principles and rules of thumb lead to an understanding of specific cases or sets of cases. This is, of course, the opposite direction from that in which the general understanding was originally established.

Suits (1972) has developed an intricate model for vegetation reflectance which agrees qualitatively but not quantitatively with measurements. This model requires a detailed statistical description of the reflectance and geometric properties of various canopy components. While it has been possible to specify the input parameters for this model for the case of crops, natural rangeland is much more complex and an accurate specification of the parameters of rangeland would be prohibitively difficult.

We must emphasize that native rangeland is a very complex ecosystem even on a small scale. Within a given 0.5 x 0.5 metre sampling area there can exist several to many different species of live green plants (grasses, forbs, and shrubs) together with standing senescent and dead vegetation, fallen dead vegetation, animal droppings in various stages of decay, and sometimes bare soil.

The geometric arrangement of these constituents and the illumination are also important in determining the spectral reflectance properties of a given area of rangeland. Our 1980 observations covered a wide range of conditions in the Mixed Grass and Fescue Prairies, but there are certainly conditions that were missed and to which the following guidelines may not apply.

B.2 FACTORS INFLUENCING THE SPECTRAL REFLECTANCE OF RANGELAND

We believe that three factors must be taken into consideration when analyzing the spectral reflectance of rangeland under the conditions encountered in this experiment (namely a clear sky with 0-30 percent cumulus cloud cover with perhaps some thin cirrus, and a solar zenith angle of 30^{o} to 60 or 70^{o}). These three factors were:

(a) the reflectance of the individual components,
(b) the geometric arrangement of the individual components, and
(c) the shadow casting efficiency of canopy components.

B.2.1 The Reflectance of Individual Components

The individual rangeland components are:

(a) live, senescing and dead leaves and stems of grasses,
(b) live and dead leaves and stems of forbs,
(c) live and dead leaves and branches of shrubs,
(d) live and senescent ground-covering, and plants such as club mosses,
(e) animal droppings, and
(f) bare soil.

The spectral reflectances of these individual rangeland components have been studied less than the spectral reflectances of cultivated plants. Nonetheless, we can apply some previous knowledge about the reflectance properties of vegetation and soils.

The spectral reflectance of live green vegetation is determined by three separate mechanisms in the reflective parts of the spectrum. In the visual range, 0.4 to 0.7 micrometre, molecular absorption bands, particularly those of chlorophyll, dominate. The centres of these bands are in the blue and red portions of the spectrum and consequently the absorption is lower than in the green. This results in the characteristic green colour of healthy live vegetation. The reflectance factor of individual leaves is low (0.15 or less) throughout this region.

In the near-infrared, 0.8 to 1.0 micrometre, the reflectance is very high. This is due to the lack of any significant molecular absorption and the multiple scattering of radiation at air-cell wall interfaces, particularly in the spongy mesophyll of the leaves.

In the mid-infrared, 1.0 to 2.5 micrometres, the molecular absorption by water is important. The two thematic mapper bands in this region, TM5 (1.55-1.75 micrometres) and TM6 (2.05-2.35 micrometres) lie between water absorption bands, but the reflectance in these TM bands is strongly affected by the presence of the wings of the water absorption bands.

In senescing and dead vegetation, the molecular absorption bands in the 0.4 to 0.7 micrometre range are reduced in strength or absent, and the reflectance increases monotonically from 0.4 to 1.0 micrometre. Beyond 1.0 micrometre, the reflectance is strongly affected by the amount of moisture and is generally higher than for live samples of the same plant.

The spectral reflectance of soils generally increases monotonically throughout the 0.4 to 2.5 micrometre range, with the slope decreasing as the wavelength increases. However, there are sometimes molecular absorptions caused by soil minerals. Moist soil is darker than dry soil of the same type throughout the 0.4 to 2.5 micrometre region, but the visible surface usually dries within a day (or less) of a rainfall.

Many variations can occur within this broad framework. For example, in the visual part of the spectrum, live and senescing bromegrasses have a different colour from most other grasses typical of the Fescue Prairie. Also, live and senescing sandgrasses have a different colour than most other grasses in the Mixed Grass Prairie. The characteristic gray colour of the sages is very distinct, and many forbs and shrubs bloom with brightly coloured flowers.

B.2.2 The Geometric Arrangement of the Individual Components

The variation in spectral reflectance introduced by geometry is even greater than that introduced by the variations in the vegetation components. Very simply stated, visible and near-infrared sensors see what is exposed. On the ground we have observed large amounts of green grass and forbs completely obscured by brown carryover, and counter examples of heavy carryover obscured by green grass and/or forbs. In such instances, a remote sensing measurement will tell little about the component that cannot be seen. However, multiple scattering of radiation can cause unseen components to affect the spectral reflectance of the canopy, although to a lesser extent than the seen components.

A related important geometric effect, especially when considering quantitative biomass estimates, is the predominantly vertical structure of grass leaves, compared with the horizontal structure of forb leaves. Unless the forbs are obscured by grasses or carryover, a lower reflectance in the 0.4 to 0.7 micrometre spectral region and a higher reflectance in the 0.8 to 1.0 micrometre region than in an equal mass of green grass will result.

Much of the scatter in the reflectance factors can be traced to these geometrical effects.

B.2.3 Shadow-Casting Efficiency of Canopy Components

Shadows cast by individual components in the instantaneous field of view (IFOV) of a sensor always decrease the reflectance factor throughout the spectrum, although the effect is lessened in the visible by the filling in of shadows by diffuse skylight, and in the near-infrared by filling in of shadows by scattering from directly illuminated constituents of the canopy.

However, the shadow-casting efficiency of individual components varies greatly. For example, a headed, senescent, crested wheatgrass plant illuminated by a relatively low sun will cast a much more prominent shadow, in a remote sensing context, than a small forb near the ground, whose shadow is mostly obscured, for vertical viewing, by the plant that casts it.

We believe that this shadowing effect is the primary reason why better areas, with more carryover, in the Mixed Grass Prairie are darker in all bands than poorer areas with less carryover. In the poorest areas, light brown soil with a particularly high reflectance becomes the dominant effect. An interesting violation of this principle occurs in areas seeded to Russian wild rye. These were not

found in the Little Bow area and hence were not measured by the V-IR Laboratory. They did occur, however, in the Bow Island lease, which was visited as part of the demonstration component of this project. Fields seeded to Russian wild rye look very bright on Landsat enhanced DCS images, even when they are in excellent condition. This is because Russian wild rye is a bunchgrass that grows with large bare soil areas between the plants. It is planted in rows up to 90 cm apart. Bunching the plants together decreases their shadowing efficiency because, in many cases, two or more shadows overlap. Hence, the highly reflective bare soil between the bunches is only partly shadowed, and causes the high reflectance recorded by Landsat.

B.3 RULES OF THUMB FOR UNDERSTANDING AND PREDICTING THE REFLECTANCE OF RANGELAND

The following rules of thumb have been extracted from a study of the reflectance spectra, two-band scatter diagrams, and bivariate regression plots generated in this project. They take the factors discussed in Section B.2 into account as parts of this quest for understanding this complex problem.

B.3.1 The Role of Green Vegetation

The presence of green vegetation decreases the reflectance in the 0.4 to 0.7 micrometre region by chlorophyll absorption, increases the reflectance in the 0.8 to 1.0 micrometre region, and generally decreases it in the 1.3 to 2.5 micrometre region. Because of their different geometries, grasses and forbs will be discussed separately.

B.3.1.1 Forbs and Shrubs

Areas that contain a dense covering of forbs and shrubs approach the characteristic reflectance spectrum of healthy green vegetation, with very low reflectance in the visible and high near-infrared reflectance. If they are large enough to fill the IFOV of a multispectral scanner, they will cause a red or bright pink tone in a colour infrared DCS image.

B.3.1.2 Grasses

Green grasses in the Mixed Grass Prairie are seldom dense enough to dominate the spectral reflectance of an area. In areas of good condition the grass is mixed with and usually partially obscured by carryover, and in poor areas there is considerable brown soil or litter between the individual clumps of green grass. Exceptions are the heavily grazed areas such as stream beds and very wet depressions that have abundant moisture. In such areas, a lush carpet of green grass can occur, which can be spectrally indistinguishable from areas of dense forbs and/or shrubs.

In the Fescue Prairie, the reflectance of grassy areas is greatly influenced by the amount of brown material present. In lightly grazed areas, the green grass can be obscured by brown carryover, approximately evenly mixed with carryover, or it can cover the carryover. Hence, the reflectance can be that of green grass,

brown carryover, or anything in between. In heavily grazed areas there is usually a significant amount of brown soil and litter between the small clumps of short green grass, athough in stream beds a closed carpet of green can occur. The reflectance can be predominantly that of green grass, brown soil and litter, or anything in between.

In short, there is a wide range of spectral reflectance in the Fescue Prairie, which gives little information about range condition in the visible and near-infrared spectral regions.

B.3.2 The Effect of Carryover

The intrinsic reflectance of carryover is higher than green vegetation in the 0.4 to 0.7 micrometre region, about the same in the 0.8 to 1.0 region and higher in the 1.3 to 2.5 micrometre region. However, as viewed in a native rangeland, the effect of carryover is much different from what this simple statement would suggest.

B.3.2.1 In the Mixed Grass Prairie

Throughout the growing season, carryover decreases the reflectance in all of the thematic mapper bands, and by inference, throughout the 0.4 to 2.5 micrometre region. As discussed in Section B.2, we believe that this is because of the great shadow-casting efficiency of the carryover, found in the Mixed Grass Prairie. Very careful, specialized measurements would be necessary to confirm this hypothesis. Since the amount of carryover is so closely related to range condition, this phenomenon makes possible the use of contrast-enhanced Landsat images as indicators of range condition, as shown in the demonstration component of this project.

B.3.2.2 In the Fescue Prairie

In dense clumps of fescue carryover, the individual blades of brown grass lean over, decreasing their shadow-casting efficiency and presenting their sides toward the vertical viewer. In the early growing season, the carryover obscures the new green growth, while in areas with little carryover, the new green is visible. The difference is most pronounced in the red part of the spectrum, where the areas of high carryover are considerably brighter than the areas of low carryover. This difference cannot be used to determine range condition, however, because the poorest areas have brown litter between short tufts of green grass and consequently are also bright in the red part of the spectrum. At the peak of the growing season, the green grass pushes above the carryover and partly or totally obscures it. When senescence has set in the entire rangeland, except for areas with dense forbs, shrubs, or trees, takes on the spectral reflectance of the carryover. At this time in the mid-infrared, there is a separation by carryover biomass, with areas of greater biomass appearing darker. We do not know whether this effect is predominantly caused by shadowing or by moisture retention in areas of greater biomass.

B.3.3 Effects of Plant Moisture

Laboratory studies have shown the reflectance in the mid-infrared region (1.3 to 2.5 micrometres) to be sensitive to plant moisture. Our bivariate regression analyses, with percentage of plant moisture defined as wet, mass-dry, mass/wet, mass, showed very low correlation with the reflectance factors in these bands. Other effects, such as shadowing or some other phenomenon related to biomass density but not to moisture content, must be obscuring any relationship. Therefore, it appears that, at least in the case of rangeland, this new spectral region cannot be used to determine vegetative moisture content.

TABLE 1

Range Site Descriptions for Alberta*

Range sites that can produce more herbage than ordinary range uplands because of superior soil moisture availability:

Wetlands- marshy lands with subirrigation where seepage, ponding, etc. raises the water table to above the surface during a part of the growing season

Subirrigated- lands with the water table rarely above the surface during the growing season but subirrigated most of the season

Overflow- areas regularly receiving more than normal soil moisture because of run-in or stream overflow and areas with water-spreading systems

Saline Lowland- subirrigated and overflow lands receiving more than normal soil moisture where salt or alkali accumulations or both are apparent and salt-tolerant plants occur over most of the area

Range sites with no obvious soil or moisture limiting factors; the vegetation can make a normal response to climate:

Sands- deep, loose, fine sands and very fine sands; surface level to rolling; excepting compact, dark, nearly level loamy fine sands and loamy very fine sands

Savannah- uplands with deep soils on which grass cover with isolated trees is normal; common at margins of forest and grassland where soil moisture favours tree growth

Sandy- all normal, coarse to fine sandy loams plus dark, nearly level loamy fine sands, and loamy very fine sands

Loamy- all normal loams, silt loams, and silts

Clayey- all normal, relatively pervious, sandy to silty clay loams and clays, normally granular

Range sites with characteristics or topographic features that limit soil moisture holding capacity or infiltration rates:

Choppy Sandhills- deep, loose, fine sands; surface very irregular with no profile development (dunes)

Limy- eroded or immature soils in which the lime layer occurs at the surface

Shallow to Gravel- shallow soils resting on clean gravelly or cobbly materials, usually in stream bottoms

Blowouts- areas where hard clays or other impervious materials lie close to or at the surface in shallow depressions that occupy 20 to 50 percent of the area (solonetz)

Thin Breaks- mixed soils of various depths with hard rock or other resistant bed outcroppings at various levels on steep irregular slopes

Gravel- coarse-textured soils with more than 50 percent gravel and small stones

Saline Upland- soils with salt or alkali accumulation or both

Badlands- nearly barren lands broken by drainages dry most of the year with intermingled grazeable areas too small to justify mapping separately

*from Smoliak et al., 1976

TABLE 2

SUMMARY OF GROUND MEASUREMENTS[1]
JUNE - OCTOBER, 1980
LITTLE BOW

Sampling Period	Transect No.	Range Condition (Subjective assessment)	Biomass in kg/ha (dry weight)					% ground surface covered by		
			Green			Litter/		Green		
			Grass	Forbs	Shrubs	C-O	Total	Vegetation[2]	Litter & Carryover	Bare Soil
June	1	Poor	485	57	12	240	794	49	35	14
	2	Good	440	200	0	465	1105	44	51	6
	4	Fair	617	123	6	423	1189	55	40	6
	5	Good	737	286	63	680	1789	50	40	4
	6	Good	688	404	0	496	1600	75	18	8
	7	Poor	456	256	24	384	1080	63	14	19
July	1	Poor	408	76	8	100	592	79	7	10
	2A	Good	633	140	0	580	1352	36	55	11
	2B	Good	548	200	0	828	1576	30	43	27
	4	Fair	708	516	0	624	1848	61	22	18
	5	Good	1145	440	0	1305	2890	68	26	6
	7	Poor	452	220	0	124	796	86	7	8
August	1	Poor	347	67	0	71	485	31	47	15
	4	Fair	332	432	0	160	924	70	12	19
	6	Good	316	152	0	216	684	77	11	13
September	1	Poor	457	130	37	136	760	38	60	4
	2A	Good	376	268	0	552	1196	41	53	7
	2B	Good	400	124	0	616	1140	39	48	14
	7	Poor	313	400	0	240	953	60	30	10
	8	Good	388	328	0	640	1356	31	65	4

Table 2 (cont'd)

Sampling Period	Transect No.	Range Condition	Biomass in kg/ha (dry weight)					% ground surface covered by		
			Green			Litter/ C-O	Total	Green Vegetation[2]	Litter & Carryover	Bare Soil
			Grass	Forbs	Shrubs					
October	1	Poor	358 (includes forbs)			128	486	-	-	-
	2	Good	514 (includes forbs)			130	644	-	-	-
	8	Good	404 (includes forbs)			166	570	-	-	-

[1]Mean of quadrats 1/4m^2 (10 quadrats per transect)

[2]includes coverage of little club moss (not included in biomass measurements)

TABLE 3

PLOT VARIABLES

1. year
2. date (month and day)
3. dominant species
4. plot number
5. spectrometer photo ID
6. scan file number
7. number of targets (5 for rangeland '80 project)
8. coordinated universal time
9. solar elevation
10. solar azimuth
11. scan azimuth
12. height above target

TARGET VARIABLES

1. viewing angle relative to nadir
2. percent green (ocular estimate)
3. percent litter (ocular estimate)
4. percent shadow (ocular estimate)
5. percent soil (ocular estimate)
6. soil moisture at 2 cm
7. soil moisture at 15 cm
8. wet litter (kg/ha)
9. wet forbs (kg/ha)
10. wet grass (kg/ha)
11. wet shrubs (kg/ha)
12. dry litter (kg/ha)
13. dry forbs (kg/ha)
14. dry grass (kg/ha)
15. dry shrubs (kg/ha)
16. soil colour
17. soil colour
18. percent carryover (ocular estimate)
19. wet carryover (kg/ha)
20. dry carryover (kg/ha)

TABLE 4

THEMATIC MAPPER BANDS

BAND	WAVELENGTH (μm)	SENSITIVE TO
1	0.45 - 0.52	chlorophyll absorption, sediment in water
2	0.52 - 0.60	chlorophyll absorption
3	0.63 - 0.69	chlorophyll absorption, brown biomass
4	0.76 - 0.90	green biomass
5	1.55 - 1.75	vegetation density and moisture
6	2.08 - 2.35	vegetation density and moisture, minerals
7	10.4 - 12.5	temperature and emissivity of surface material

Location: Little Bow **Growth Stage: Early growth (June)**

Site type, condition, and description	Example	Factors determining band reflectance				Resulting Appearance (on colour infrared imagery)
		TM2	TM3	TM4	TM5	
1. Knoll top, poor condition. Club moss base with varying amounts of bare soil, sparse, short tufts of green grass, negligible carryover from last year	LB 4	8-12	9-13	17-22	22-28	light gray
		reflectance of club moss and soil in appropriate proportions				
2. Native range, fair conditon. Club moss base with varying amounts of bare soil. Mixture of green vegetation and brown carryover in roughly equal amounts. Green growth contains a relatively high proportion of forbs	LB 5, LB 10	7-9	8-10	20-25	18-21	gray to pink depending on amount of green vegetation
		low because of chloropyll absorption		high because of green vegetation	low because of green vegetation	
3. Native range, good contition. Green grass coming up under brown carryover. Cannot see ground. Few forbs	LB 9	7-9	8-10	17-19	20-23	gray or dark cyan
		decreased by chlorophyll absorption		decreased by carryover	decreased by carryover but higher than poor areas	
4. Range improved with crested wheat-grass. Excellent conditon. Green nearly hidden under heavy carryover. Cannot see ground. Few forbs	LB 3	7-8	8-9	15-18	18-20	dark gray
		decreased by carryover in all bands				
5. Stabilized dune with sandgrass cover. Lots of coarse, light orange-brown carryover against dark brown background. Green grass coming up underneath	LB 6	8-10	9-11	22-25	22-25	pink
		increased by sandgrass carryover, decreased by chloropyll absorption and dark brown background. Result is mid-range		high	mid-range	
6. Dense patch of forbs or shrubs. Dense canopy of green vegetation	LB 7	5-7	6-8	23-25	20-23	pink to red
		decreased by chlorophyll absorption		high because of green vegetation	low because of dense vegetation	
7. Dense patch of pasture sage	None measured in June.					

Table 5a

Location: Little Bow **Growth Stage: Peak of green (July)**

Site type, condition, and description	Example	Factors determining band reflectance				Resulting Appearance (on colour infrared imagary)
		TM2	TM3	TM4	TM5	
1. Native range, poor condition sparse green grass, against club moss background with carrying amounts of bare soil.	LB 4,10,11,13	8-10 high because of sparse vegetation,	9.5-11	19-25 bare soil	23-30	light pink to light gray
2. Native range, fair condition. Green brown mixture on club moss background. Some forbs	LB 15	7.5-9 some chlorophyll absorption	8.5-10	16-20 lower than 1, because of carryover	20-23 slightly lower than 1 because of more vegetation	light cyan to pinkish gray depending on density of forbs
3. Native range, good condition. Green brown mixture covers ground. Few forbs.	LB 8	5.5-7.5 low because of chlorophyll and carryover	6-8.5	15-21 decreased by carryover, increased by green. Result is mid-range	22-28 mid-range	gray to dark cyan
4. Range improved with wheatgrass. Excellent condition current year's growth already brown nearly to base.	LB 3	6.5-7.5 low because of carryover	7-9	14-16 decreased by carryover	17-21 low because of dense vegetation	dark gray
5. Stabilized dune with sandgrass cover. Less orange brown carryover than early season. More green grass more dark brown matter between the green than in June	LB 6	8-9 moderately high because of bright carryover	9-10	21-23 moderately high because of green vegetation	20-22 moderately low because of dense vegetation	pink to light gray
6. Patch of forbs or shrubs. Open to dense canopy of green vegetation	LB 5,7	5-6.5 low to medium low because of chlorophyll absorption	5-7	24-28 high because of green vegetation	14-18 low because of dense vegetation	bright pink to red
7. Dense patch of pasture sage.	none measured in July					

Table 5b

Location: Little Bow **Growth Stage: Beginning senescence (August)**

Site type, condition, and description	Example	Factors determining band reflectance				Resulting Appearance (on colour infrared imagary)
		TM2	TM3	TM4	TM5	
1. Native range, poor condition sparse to moderate green grass above club moss background, with varying amounts of bare soil. Sometimes forbs. Some senescence of grass.	LB 13,14	9.5-12 some chlorophyll absorption depending on green grass and forb density	9.5-13	19-22 medium	28-32 high	light gray
2. Native range, fair condition. Green grass and brown carryover against club moss background. Fewer forbs than at peak of green.	LB 11, 15	9-11 wide range depending on amounts of green	9.5-13	22-24 higher than 1 because of green vegetation	30-34	light gray to light pink depending on green/brown ratio
3. Native range, good condition. Good brown carryover, some green grass and forbs mixed in.	LB 16	8.5-9.5 carryover controls brightness	10-12	18-20 lower than 1 and 2 because of carryover	25-29 lower than 1 and 2 because more vegetation	gray
4. Range improved with crested wheatgrass. Excellent condition. Dense green and brown mixture. Ground not visible.	LB 16A	7-8	9-10	15-19	20-24	dark gray
		low because of dense carryover and chlorophyll and water absorption				
5. Stabilized dune with sandgrass cover. Green sandgrass with brown background, orange-brown carryover		8-9 low because of chlorophyll absorption	8-9	20-25 green vegetation	23-25 dense vegetation decreases reflectance	gray
6. Patch of forbs or shrubs, forbs less prevalent than at peak of green. Shrubs still green.	no observation in August	low	low	high	low	pink to red
7. Dense prevalence of pasture sage.	LB 18	8-9 low because of shadowing, chlorphyll absorption	8.5-10	20-22 shadowing decreases reflectance in this band	25-28	gray

Table 5c

Location: Little Bow **Growth Stage: Senescence (September)** **Note: carryover refers to this year's growth**

Site type, condition, and description	Example	Factors determining band reflectance				Resulting Appearance (on colour infrared imagery)
		TM2	TM3	TM4	TM5	
1. Native range, poor condition sparse carryover against club moss background, with varying amounts of bare soil.	LB 13, 14	10-12	12.5-14.5	20-24	32-37	light gray to white
		bright because of low carryover, dry				
2. Native range, fair condition moderate needle-and-thread and wheatgrass carryover over club moss background.	LB 4,5	7-9	9-12	17-24	26-33	gray
		darker than 1 because of carryover				
3. Native range, good condition thick needle-and-thread and wheatgrass carryover, ground not visible	LB 16	7-9	9-12	19-21	30-33	gray
		not distinguishable from 2 spectrally				
4. Range improved with crested wheatgrass, excellent condition dense cwg. carryover	LB 16A	6-8	7-10	21-26	25-33	dark gray
		shadowing by carryover reduces reflectance in all bands but brighter than August because of senescence				
5. Stabilized sand dune with sandgrass cover. Lots of orange-brown carryover on dark brown background. A few green leaves	LB 6	7.5-10.5	11-13	20-22	24-32	varying shades of gray, confused with fair-good condition
		carryover decreases reflectance slightly, but the stems and blades are intrinsically bright				
6. Patch of shrubs or forbs. Forbs mostly gone. Some shrubs have green leaves, others have brown or no leaves	LB 7	3-6 low to medium depending on density and presence of green litter	3-5	15-27 low to high depending on presence of green leaves	12-20 low because of dense vegetation	dark gray to red depending on presence of green leaves. Could be confused with good-excellent range but shrub patches usually small
7. Dense stand of fringed sage. Sage is still its typical bluish gray colour	LB 18	6-7	8-9 low because of shadowing	21-25 high because plants still growing	25-29 low because of dense vegetation	

Table 5d

Location: Ross Lake Growth Stage: Early Growth (June)

Site type, condition, and description	Example	Band Reflectance (percent) and Controlling Factors				Resulting Appearance (on colour infrared imagery)
		TM2	TM3	TM4	TM5	
Poor pasture. Mixture of short green grass, litter, and forbs	RL-1	5-7 reduced by chlorophyll absorption	5-7	20-24 low, vegetation fairly sparse	20-24 low because of vegetation	gray to pink
Dense growth of forbs and shrubs	RL-4	4-6 reduced by chlorophyll absorption	4-6	33-36 high because of green vegetation	18-22 low because of dense vegetation	red
Lightly grazed, excellent condition Heavy cover of light brown carryover with some green coming up underneath	RL-3	7-10 bright carryover masks chlorophyll absorption	7-11	18-24 low because green vegetation masked by brown	21-30 bright, carry-over highly reflective and dry	pinkish gray

Table 6a

Location: Ross Lake **Growth Stage: Maximum green growth (July)**

Site type, condition, and description	Example	Band Reflectance (percent) and Controlling Factors				Resulting Appearance (on colour infrared imagery)
		TM2	TM3	TM4	TM5	
Poor pasture. Mixture of short green grass, brown litter, and varying amounts of forbs	RL-5, RL-9	8-11 brown fills chlorophyll	7-10 in absorption	20-25 low because of reduced green vegetation	19-27 higher than areas with denser vegetation	gray to pink
Poor pasture with lots of forbs against short green grass and brown litter background.	RL-1	6-9 reduced by chlorphyll absorption	5-8	30-40 high because of green vegetation	22-32 wide range depending on forb density	gray to pink
Dense growth of forbs and shrubs	RL-4	5-7 low because of chlorophyll and shadowing	4-7	25-32 increased by green vegetation but decreased by shadowing Result is mid-range	15-19 reduced by dense vegetation	red
Lightly grazed, excellent condition large amount of brown carryover with varying amounts of green grass mixed in	RL-3, 7, 8	6-9 wide range depending on amount of green	7-11	20-30 wide range depending on amount of green	17-30 wide range depending on amount of green	gray to pink depending on amount of green grass

Table 6b

Location: Rose Lake **Growth Stage: Beginning senescence (August)**

Site type, condition, and description	Example	Band Reflectance (percent) and Controlling Factors				Resulting Appearance (on colour infrared imagery)
		TM2	TM3	TM4	TM5	
Poor condition. Mixture of short green grass, litter, variable amount of forbs	RL-5A,10,11	7-12 depending on amount of vegetation. Bare is brighter	8-15	21-29 depending on amount of vegetation. Bare is brighter	22-42 depending on amount of vegetation. Bare is brighter	light to dark gray, pink if many forbs
Dense growth of forbs or shrubs	RL-14	5-7 reduced by chlorophyll absorption	4-7	28-32 high from green vegetation	15-20 low because of dense vegetation	pink to red
Lightly grazed, excellent condition dense brown carryover, mixed with green grass with brown tips	RL-15,16	7-10 lower if more green	8-12	22-32 wide range depending on amount of green	19-28	gray to pink

Table 6c

Location: Ross Lake **Growth Stage: Senescence (September)**

Site type, condition, and description	Example	Band Reflectance (percent) and Controlling Factors				Resulting Appearance (on colour infrared imagery)
		TM2	TM3	TM4	TM5	
Poor pasture. Small amount of short green grass, mostly brown litter, variable amount of forbs	RL-10, 5A, 11	8-11 ---------	10-17 low if forbs and shrubs, high if quite bare	20-25	28-42 ----------	gray to pink
Areas with dense forbs and shrubs. Snowberry, especially, persists until September, but leaves mostly brown or gone	RL-4	6.5-7.5 low because of vegetation density, chlorophyll absorption, dark colour	8-10	16-24 variable depending on amount of green vegetation	24-28 low because of dense vegetation	gray to pink
Lightly grazed, excellent condition. Dense brown carryover with a few blades of green grass	RL-15, 16	8-11 variation seems to be caused by canopy configuration and density, not by amount of green	10-14	18-24	23-30 low because of dense vegetation. This is where good and poor range can be separated	gray to pink

Table 6d

Location: Stavely **Growth Stage: Early growth (June)**

Site type, condition, and description	Example	Band Reflectance (percent) and Controlling Factors				Resulting Appearance (on colour infrared imagery)
		TM2	TM3	TM4	TM5	
Very heavily grazed poor condition. Mixture of short green grass, small forbs, bare soil and some litter	SD-1	6-9 brown partly decreasing chlorophyll absorption	7-10	24-30 green and brown both fairly bright	27-30 brightest area measured	darker than surroundings, blush pink
Heavily grazed, mixture of green grass, brown carryover, and forbs in approx. equal amounts. No bare soil	SC-1	5-9 brown partly decreasing chlorophyll absorption	6-10	21-26 brown partly decreasing high IR reflectance of green vegetation	20-26 wide range in TM5 reflectance	pink
Moist areas, heavy green forb and/or grass growth, little or no carryover	SB-1 SB-2 SC-2	4-6 low from chlorophyll absorption	3.5-7	26-30 high from green vegetation	11-27 low where pure green, higher where some carryover	bright red
Lightly grazed. Heavy brown carryover generally masks green	SA-2, SA-1	7-11 brown decreases chlorophyll absorption. Sensitive to amount of green showing	8-12	21-24 brown decreases high IR reflectance of green vegetation. Not sensitive to amount of green	17-23 intermediate between poor areas and dense green areas	pink
Lightly grazed areas of brome grass. Mixture of green grass and brown carryover similar to SC-1, SA-2. Less biomass than lightly grazed fescue	SE-0, SE-2	6-10 brown decreasing chlorophyll absorption. Sensitive to amount of green grass showing through brown	5-11	21-25 brown decreasing high IR reflectance of green vegetation. Not sensitive to amount of green	19-21 intermediate narrow range	pink

Table 7a

Location: Stavely **Growth Stage: Maximum green growth (July)**

Site type, condition, and description	Example	Band Reflectance (percent) and Controlling Factors				Resulting Appearance (on colour infrared imagery)
		TM2	TM3	TM4	TM5	
Very heavily grazed, poor condition. Sparse, short green grass, some forbs, little pieces of brown litter covering ground in between	SD-1, SD-2,	7-9 brown litter is dominant effect	7-11	24-28 lower than green areas	24-30 brightest area measured	light gray
Heavily grazed. Mixture of short green grass, forbs, and brown litter in approximately equal amounts	SA-3	5-7 brown partly decreasing chlorophyll absorption	5-7	24-27 lower than green areas	18-24 mid-range	grayish pink to pinkish gray depending on red colour balance
Areas with heavy green forb and/or grass growth, some brown litter mixed in	SB-1, SB-2 SC-2	6-7.5 low from chlorophyll absorption, higher if more brown	6-8	30-36 high from green vegetation	17-25 wide range, cause unknown	red
Lightly grazed. Heavy green grass and carryover, green generally above carryover	SA-1, SA-2, SC-3	5-7 low from chlorophyll absorption, higher if more brown	4-7	26-30 lower than forb areas, probably because of shadowing	16-23 wide range - cause may be moisture	pink to gray depending on colour balance very similar to heavily grazed areas
Lightly grazed bromegrass	SE-2	5-6	4.5-6	24-26	17-20	pink
Timothy	SE-0	5-6	4.5-6	34-36	24-27	brownish pink

Table 7b

Location: Stavely **Growth Stage: Early senescence (August)**

Site type, condition, and description	Example	Band Reflectance (percent) and Controlling Factors				Resulting Appearance (on colour infrared imagery)
		TM2	TM3	TM4	TM5	GRI
Very heavily grazed, poor condition. Sparse short green grass, small forbs, with brown litter covering the ground	SD-1, SD-2	7-11 brown litter is dominant effect	8-12	27-32 among the highest areas in this band	31-44 brightest measured	light bluish gray
Heavily grazed. Mixture of short green grass, forbs, and litter in approximately equal amounts.	SC-2	6-8 brown partly filling in chlorophyll absorption	7-9	27-32 similar to poor areas	27-32 darker than poor areas because more biomass	gray
Areas which had heavy growth of forbs and/or green grass in stream bed. These now have fewer green forbs, more dead remains of forbs, and grass in stream bed looks browner.	SB-1, SB-2	4-7 brown decreases chlorophyll absorption	4-7	23-26 loss of green vegetation, perhaps onset of senescence, increase in brown have caused dramatic decrease since July	19-24 among the lowest areas in this band	gray, darker than heavily grazed
Lightly grazed, high biomass area. Grass is green with brown tips of blades above heavy brown carryover background. More brown than green.	SA-2, SC-3	5-7.5 brown decreases chlorophyll absorption	5-8	25-28 has decreased since July because of onset of senescence	23-31 intermediate range	gray

Table 7c

Location: Stavely **Growth Stage: Senescence (September)**

Site type, condition, and description	Example	Band Reflectance (percent) and Controlling Factors				Resulting Appearance (on colour infrared imagery)
		TM2	TM3	TM4	TM5	
Very heavily grazed. Poor condition. Very short, brown grass and litter, a few blades of green grass and a few green forbs	SD-1, SD-2	7-9.5 low chlorophyll, brown spectrum dominates	9-12 absorption by green vegetation	24-30 reduced reflection wide range	31-38 bright but wide range	light pinkish gray
Heavily grazed. Mixture of short brown grass with some green blades, brown litter, a few green forbs	SC-2	6-8 brown litter and carryover dominent, more shadow than SB-1 and SB-2	7-10	19-24 reflectance by green vegetation in this band	25-30 shadows and moisture retention reduce reflectance	gray
Areas with heavy growth of forbs, many forbs gone, remainder mostly brown though some still green. Gross mostly brown, but some green.	SB-1	8-9.5 brown dominates	10-12	30-34 browner than August yet brighter in this band. Cause unknown	32-40	light pink
Stream bed. Short green grass mixed with short brown grass	SB-2	6-7.5 some chlorophyll absorption	7.5-9	34-36 high reflectance of green vegetation. Has greened-up since August. Sensitive to rainfall	34-38	pink
Lightly grazed. Heavy brown carryover with a few blades of green grass and a few forbs	SA-2, SC-3	8-12 light brown carryover fills in chlorophyll absorption. Wide range in this band	10-15	18-29 lower than green vegetation because of carryover	22-29 low because of vegetation density	light gray
Lightly grazed bromegrass, heavy carryover with some green grass at base. Carryover is dark brown	SE-2	6-7.5 shadowing by brown carryover, some chlorophyll absorption	7.5-9	19-24 low because carry-over is dark and causes shadows absorption	27-30 low because of dense vegetation	light gray
Lightly grazed oat grass, heavy carryover with some green grass. Carryover is light brown		9.5-12 bright because carryover is bright	12-15	21-27 negligible reflect-ance by green vegetation, carryover dominates	27-30 low because of dense vegetation	light gray

Table 7d

***** CORRELATION MATRIX *****

VAR.													
WTOT	1.0000												
WGFS	0.9274	1.0000											
WLC	0.7190	0.4067	1.0000										
WG	0.8217	0.6658	0.7694	1.0000									
WF	0.5283	0.7661	-0.1330	0.0310	1.0000								
SLM12	0.3353	0.2966	0.2678	0.3120	0.1251	1.0000							
PV	0.3269	0.3361	0.1739	0.4161	0.0990	0.3441	1.0000						
T1	-0.6944	-0.7079	-0.3805	-0.6744	-0.3717	-0.3108	-0.5286	1.0000					
T2	-0.6540	-0.6837	-0.3269	-0.6523	-0.3597	-0.3320	-0.4872	0.9881	1.0000				
T3	-0.6306	-0.6947	-0.2495	-0.6126	-0.4102	-0.3114	-0.5531	0.9785	0.9883	1.0000			
T4	0.0356	0.1794	-0.2461	-0.2293	0.4394	-0.2447	0.3447	0.0442	0.1294	0.0275	1.0000		
T5	-0.2530	-0.3426	0.0187	-0.3786	-0.1443	-0.1692	-0.3179	0.6437	0.7207	0.7451	0.1862	1.0000	
T6	-0.3043	-0.3837	-0.0301	-0.3899	-0.1880	-0.1884	-0.5126	0.6881	0.7319	0.7760	-0.1082	0.9255	1.0000
	WTOT	WGFS	WLC	WG	WF	SLM12	PV	T1	T2	T3	T4	T5	T6

WTOT	Total wet weight of biomass	WF	Wet weight of forbs
WGFS	Wet weight of green biomass (grass, forbs, and shrubs)	SLM12	Average soil moisture at the depth (2 cm and 15 cm)
WLC	Wet weight of brown biomass (litter and carryover)	PV	Visual estimate of percent green in spectrometer field of view
WG	Wet weight of grass	T1 - T6	Reflectance factor in thematic mapper bands 1 through 6.

Table 8a

***** CORRELATION MATRIX *****

VAR.	WTOT	WGFS	WLC	WG	WF	SLM12	PV	T1	T2	T3	T4	T5	T6
WTOT	1.0000												
WGFS	0.9537	1.0000											
WLC	0.8000	0.5824	1.0000										
WG	0.8548	0.7620	0.7898	1.0000									
WF	0.6321	0.7882	0.1361	0.2068	1.0000								
SLM12	0.4270	0.4680	0.2203	0.3980	0.3337	1.0000							
PV	0.4328	0.3871	0.3976	0.3781	0.2185	0.2384	1.0000						
T1	-0.9118	-0.8982	-0.6724	-0.8333	-0.5643	-0.3983	-0.4019	1.0000					
T2	-0.8902	-0.8805	-0.6493	-0.8500	-0.5238	-0.4102	-0.3124	0.9718	1.0000				
T3	-0.8765	-0.9039	-0.5657	-0.7990	-0.6022	-0.4935	-0.3612	0.9759	0.9613	1.0000			
T4	0.1002	0.1734	-0.0750	-0.1775	0.3992	-0.0413	0.3780	-0.0549	0.1304	-0.0727	1.0000		
T5	-0.6409	-0.7254	-0.2849	-0.6022	-0.5253	-0.6006	-0.0252	0.6984	0.7785	0.7689	0.2535	1.0000	
T6	-0.6737	-0.7582	-0.3084	-0.6216	-0.5539	-0.6683	-0.1085	0.7239	0.7761	0.8030	0.1225	0.9815	1.0000

WTOT Total wet weight of biomass

WGFS Wet weight of green biomass (grass, forbs, and shrubs)

WLC Wet weight of brown biomass (litter and carryover)

WG Wet weight of grass

WF Wet weight of forbs

SLM12 Average soil moisture at the depth (2 cm and 15 cm)

PV Visual estimate of percent green in spectrometer field of view

T1 - T6 Reflectance factor in thematic mapper bands 1 through 6.

Table 8b

***** CORRELATION MATRIX *****

VAR.															
WTOT	1.0000														
WGFS	0.8829	1.0000													
WLC	0.8247	0.4624	1.0000												
WL	0.7376	0.4545	0.9451	1.0000											
WC	0.7231	0.3745	0.9142	0.5560	1.0000										
WG	0.7908	0.7386	0.6035	0.3485	0.6741	1.0000									
WF	0.2657	0.4322	-0.0189	0.2097	-0.1876	-0.1044	1.0000								
SLM12	0.4618	0.1647	0.6735	0.6562	0.5498	0.3390	-0.0558	1.0000							
PV	0.5197	0.5379	0.3333	0.1925	0.3724	0.5374	-0.0648	0.1005	1.0000						
T1	-0.7485	-0.6316	-0.6525	-0.4876	-0.6449	-0.7012	0.0287	-0.3936	-0.6597	1.0000					
T2	-0.6361	-0.4295	-0.6837	-0.5645	-0.6350	-0.5072	0.1040	-0.5038	-0.4529	0.9279	1.0000				
T3	-0.5933	-0.5266	-0.4860	-0.3372	-0.5001	-0.5698	0.0377	-0.2116	-0.5861	0.9513	0.9033	1.0000			
T4	-0.0540	0.3046	-0.4688	-0.3851	-0.4371	0.0272	0.4476	-0.4694	0.2521	0.2206	0.5334	0.2359	1.0000		
T5	-0.6587	-0.4359	-0.7186	-0.5489	-0.7013	-0.4732	0.0661	-0.4041	-0.3679	0.8344	0.8817	0.8280	0.4908	1.0000	
T6	-0.7605	-0.6046	-0.7076	-0.5324	-0.6967	-0.6231	-0.0108	-0.3365	-0.4525	0.9014	0.8845	0.8798	0.3447	0.9461	1.0000
	WTOT	WGFS	WLC	WL	WC	WG	WF	SLM12	PV	T1	T2	T3	T4	T5	T6

WTOT Total wet weight of biomass

WGFS Wet weight of green biomass (grass, forbs, and shrubs)

WLC Wet weight of brown biomass (litter and carryover)

WG Wet weight of grass

WF Wet weight of forbs

SLM12 Average soil moisture at the depth (2 cm and 15 cm)

PV Visual estimate of percent green in spectrometer field of view

T1 - T6 Reflectance factor in thematic mapper bands 1 through 6

WL Wet weight of litter

WC Wet weight of carryover.

Table 8c

***** CORRELATION MATRIX *****

VAR.	WTOT	WGFS	WLC	WL	WC	WG	WF	SLM12	PV	T1	T2	T3	T4	T5	T6
WTOT	1.0000														
WGFS	0.9796	1.0000													
WLC	0.7989	0.6616	1.0000												
WL	0.8010	0.6916	0.9180	1.0000											
WC	0.1081	0.0223	0.3362	-0.0648	1.0000										
WG	0.7733	0.7390	0.6733	0.7354	-0.0524	1.0000									
WF	0.3640	0.4910	-0.1113	-0.1077	-0.0243	-0.0876	1.0000								
SLM12	0.0146	0.0537	-0.1062	-0.0240	-0.2103	-0.0647	0.2648	1.0000							
PV	0.2443	0.2448	0.1788	0.2201	-0.0728	0.1148	0.2284	0.3758	1.0000						
T1	-0.5875	-0.5518	-0.5402	-0.5958	0.0556	-0.5862	0.0404	-0.2667	-0.4021	1.0000					
T2	-0.4993	-0.4870	-0.4052	-0.4769	0.1129	-0.4204	-0.0283	-0.3280	-0.3935	0.9646	1.0000				
T3	-0.4455	-0.4581	-0.2908	-0.3903	0.1952	-0.3383	-0.1427	-0.4285	-0.4330	0.9257	0.9763	1.0000			
T4	-0.1524	-0.1543	-0.1065	-0.1137	0.0021	-0.0979	0.1732	0.2715	0.2226	0.3508	0.4754	0.3601	1.0000		
T5	-0.5892	-0.5993	-0.4046	-0.3862	-0.1010	-0.4872	-0.1580	0.0720	-0.0448	0.7310	0.7594	0.6914	0.6888	1.0000	
T6	-0.4723	-0.4343	-0.4621	-0.6085	0.2824	-0.5661	0.0692	-0.1635	-0.4417	0.8060	0.7091	0.7163	-0.0481	0.4431	1.0000

WTOT Total wet weight of biomass

WGFS Wet weight of green biomass (grass, forbs, and shrubs)

WLC Wet weight of brown biomass (litter and carryover)

WG Wet weight of grass

WF Wet weight of forbs

SLM12 Average soil moisture at the depth (2 cm and 15 cm)

PV Visual estimate of percent green in spectrometer field of view

T1 - T6 Reflectance factor in thematic mapper bands 1 through 6

WL Wet weight of litter

WC Wet weight of carryover.

Table 8d

***** CORRELATION MATRIX *****

VAR.													
WTOT	1.0000												
WGFS	0.8053	1.0000											
WLC	0.9899	0.7130	1.0000										
WG	0.9902	0.8269	0.9732	1.0000									
WF	-0.8257	-0.3687	-0.8882	-0.8179	1.0000								
SLM12	0.5143	0.5971	0.4653	0.5264	-0.3547	1.0000							
PV	-0.4953	-0.0045	-0.5847	-0.4397	0.7887	-0.3139	1.0000						
T1	0.4132	-0.1445	0.5232	0.4049	-0.7912	-0.0747	-0.7115	1.0000					
T2	0.4767	-0.0730	0.5812	0.4750	-0.8349	0.0176	-0.7107	0.9907	1.0000				
T3	0.5007	-0.0585	0.6061	0.4920	-0.8529	0.0108	-0.7453	0.9935	0.9954	1.0000			
T4	0.5012	0.3482	0.5094	0.5136	-0.4372	0.3372	-0.1375	0.3246	0.4282	0.3670	1.0000		
T5	0.6077	0.1257	0.6885	0.5976	-0.8809	0.4259	-0.7684	0.8519	0.8963	0.8912	0.5107	1.0000	
T6	0.4547	-0.0418	0.5477	0.4449	-0.7975	0.3357	-0.7380	0.8746	0.9050	0.8957	0.4411	0.9821	1.0000
	WTOT	WGFS	WLC	WG	WF	SLM12	PV	T1	T2	T3	T4	T5	T6

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WTOT Total wet weight of biomass

WGFS Wet weight of green biomass (grass, forbs, and shrubs)

WLC Wet weight of brown biomass (litter and carryover)

WG Wet weight of grass

WF Wet weight of forbs

SLM12 Average soil moisture at the depth (2 cm and 15 cm)

PV Visual estimate of percent green in spectrometer field of view

T1 - T6 Reflectance factor in thematic mapper bands 1 through 6.

Table 9a

***** CORRELATION MATRIX *****

VAR.															
WTOT	1.0000														
WGFS	0.8992	1.0000													
WLC	0.7900	0.4422	1.0000												
WL	0.7923	0.4623	0.9765	1.0000											
WC	0.7259	0.3804	0.9551	0.8688	1.0000										
WG	0.8661	0.6912	0.8070	0.7718	0.7931	1.0000									
WF	0.3560	0.6793	-0.2221	-0.1570	-0.2942	-0.0543	1.0000								
SLM12	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000							
PV	-0.4925	-0.1526	-0.7958	-0.7453	-0.8037	-0.5013	0.3107	0.0000	1.0000						
T1	-0.7310	-0.7403	-0.4614	-0.4654	-0.4202	-0.7269	-0.3289	0.0000	0.1982	1.0000					
T2	-0.7067	-0.7228	-0.4361	-0.4480	-0.3860	-0.6298	-0.3970	0.0020	0.2273	0.9552	1.0000				
T3	-0.5880	-0.7459	-0.1602	-0.1840	-0.1150	-0.4838	-0.5787	0.0015	-0.1563	0.8930	0.8974	1.0000			
T4	0.4892	0.7116	0.0053	0.0547	-0.0628	0.2299	0.7347	0.0059	0.2729	-0.4120	-0.3174	-0.5572	1.0000		
T5	-0.5819	-0.5050	-0.4854	-0.4594	-0.4837	-0.6611	-0.0316	0.0020	0.4116	0.5771	0.6453	0.4699	0.1422	1.0000	
T6	-0.7848	-0.7054	-0.6205	-0.5998	-0.6009	-0.8067	-0.1592	0.0000	0.4766	0.7374	0.7693	0.6066	-0.1067	0.9482	1.0000
	WTOT	WGFS	WLC	WL	WC	WG	WF	SLM12	PV	T1	T2	T3	T4	T5	T6

WTOT Total wet weight of biomass

WGFS Wet weight of green biomass (grass, forbs, and shrubs)

WLC Wet weight of brown biomass (litter and carryover)

WG Wet weight of grass

WF Wet weight of forbs

SLM12 Average soil moisture at the depth (2 cm and 15 cm)

PV Visual estimate of percent green in spectrometer field of view

T1 - T6 Reflectance factor in thematic mapper bands 1 through 6

WL Wet weight of litter

WC Wet weight of carryover.

Table 9b

***** CORRELATION MATRIX *****

VAR.															
WTOT	1.0000														
WGFS	0.8871	1.0000													
WLC	0.9645	0.7347	1.0000												
WL	0.9148	0.7051	0.9432	1.0000											
WC	0.8534	0.6382	0.8911	0.6898	1.0000										
WG	0.9202	0.7617	0.9189	0.7846	0.9311	1.0000									
WF	0.2472	0.4097	0.1301	0.2952	-0.1197	-0.0412	1.0000								
SLM12	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000							
PV	0.1972	0.1999	0.1760	0.2607	0.0274	0.0058	0.5357	0.0000	1.0000						
T1	-0.2404	-0.2411	-0.2162	-0.1823	-0.2222	-0.2819	-0.1230	0.0000	0.3971	1.0000					
T2	-0.0754	-0.1177	-0.0438	-0.0430	-0.0366	-0.1006	-0.1156	0.0010	0.4255	0.9596	1.0000				
T3	-0.1494	-0.2205	-0.0941	-0.0813	-0.0940	-0.1391	-0.2169	0.0010	0.3025	0.9365	0.9682	1.0000			
T4	0.2029	0.2317	0.1663	0.1020	0.2232	0.1443	0.1720	-0.0039	0.3914	0.3976	0.5851	0.5224	1.0000		
T5	-0.5660	-0.5551	-0.5160	-0.4512	-0.5083	-0.5453	-0.3748	0.0039	-0.1096	0.6570	0.6332	0.7345	0.3601	1.0000	
T6	-0.6320	-0.6149	-0.5790	-0.4981	-0.5815	-0.6237	-0.3593	0.0000	-0.1198	0.6318	0.5801	0.6820	0.2865	0.9914	1.0000
	WTOT	WGFS	WLC	WL	WC	WG	WF	SLM12	PV	T1	T2	T3	T4	T5	T6

WTOT Total wet weight of biomass

WGFS Wet weight of green biomass (grass, forbs, and shrubs)

WLC Wet weight of brown biomass (litter and carryover)

WG Wet weight of grass

WF Wet weight of forbs

SLM12 Average soil moisture at the depth (2 cm and 15 cm)

PV Visual estimate of percent green in spectrometer field of view

T1 - T6 Reflectance factor in thematic mapper bands 1 through 6

WL Wet weight of litter

WC Wet weight of carryover.

Table 9c

***** CORRELATION MATRIX *****

VAR.															
WTOT	1.0000														
WGFS	0.9069	1.0000													
WLC	0.8393	0.5320	1.0000												
WL	0.8088	0.5445	0.9228	1.0000											
WC	0.7759	0.4676	0.9558	0.7687	1.0000										
WG	0.8507	0.7117	0.7911	0.6669	0.8043	1.0000									
WF	0.0767	0.2548	-0.2262	-0.1558	-0.2566	-0.2775	1.0000								
SLM12	0.3213	0.3118	0.2433	0.3871	0.1084	-0.0480	0.3655	1.0000							
PV	-0.4234	-0.1857	-0.6113	-0.4266	-0.6891	-0.4563	-0.0628	0.0527	1.0000						
T1	-0.5229	-0.6623	-0.1962	-0.2750	-0.1159	-0.3321	-0.2307	-0.1337	-0.0696	1.0000					
T2	-0.2995	-0.4047	-0.0796	-0.1424	-0.0235	-0.1559	-0.2333	0.0554	0.0583	0.9087	1.0000				
T3	-0.2830	-0.4031	-0.0486	-0.1166	0.0083	-0.0742	-0.3628	-0.0360	0.0969	0.8556	0.9699	1.0000			
T4	-0.3745	-0.2758	-0.3966	-0.3249	-0.4105	-0.3291	-0.1270	0.0892	0.6555	0.4498	0.6669	0.7114	1.0000		
T5	-0.6810	-0.5694	-0.6338	-0.4986	-0.6717	-0.6341	-0.0425	-0.0426	0.6903	0.4571	0.4882	0.5231	0.8251	1.0000	
T6	-0.7774	-0.6690	-0.6989	-0.5677	-0.7270	-0.7119	-0.0608	-0.0710	0.6741	0.4948	0.4558	0.4739	0.7307	0.9780	1.0000
	WTOT	WGFS	WLC	WL	WC	WG	WF	SLM12	PV	T1	T2	T3	T4	T5	T6

WTOT Total wet weight of biomass

WGFS Wet weight of green biomass (grass, forbs, and shrubs)

WLC Wet weight of brown biomass (litter and carryover)

WG Wet weight of grass

WF Wet weight of forbs

SLM12 Average soil moisture at the depth (2 cm and 15 cm)

PV Visual estimate of percent green in spectrometer field of view

T1 - T6 Reflectance factor in thematic mapper bands 1 through 6

WL Wet weight of litter

WC Wet weight of carryover.

Table 9d

***** CORRELATION MATRIX *****

VAR.													
WTOT	1.0000												
WGFS	0.4043	1.0000											
WLC	0.8667	-0.1060	1.0000										
WG	0.6104	0.4144	0.4376	1.0000									
WF	-0.0814	0.7568	-0.5014	-0.2080	1.0000								
SLM12	0.2835	0.4005	0.0898	0.0253	0.3722	1.0000							
PV	-0.6195	0.0827	-0.7186	-0.5506	0.5184	0.0660	1.0000						
T1	0.1246	-0.4674	0.3904	0.1981	-0.7000	-0.1808	-0.3083	1.0000					
T2	0.0725	-0.4471	0.3226	0.1855	-0.6497	-0.2217	-0.2330	0.9872	1.0000				
T3	0.0575	-0.4553	0.3108	0.1971	-0.6746	-0.1913	-0.2424	0.9887	0.9844	1.0000			
T4	-0.3474	-0.0125	-0.3709	-0.3535	0.2914	-0.1239	0.6140	0.0153	0.1465	0.0451	1.0000		
T5	-0.4541	-0.8521	-0.0289	-0.4175	-0.5931	-0.4774	0.1128	0.6219	0.6534	0.6167	0.3604	1.0000	
T6	0.5989	0.3350	0.4684	0.5705	-0.0328	-0.1452	-0.4978	0.2364	0.2723	0.2018	-0.0688	-0.2133	1.0000
	WTOT	WGFS	WLC	WG	WF	SLM12	PV	T1	T2	T3	T4	T5	T6

WTOT	Total wet weight of biomass	WF	Wet weight of forbs
WGFS	Wet weight of green biomass (grass, forbs, and shrubs)	SLM12	Average soil moisture at the depth (2 cm and 15 cm)
WLC	Wet weight of brown biomass (litter and carryover)	PV	Visual estimate of percent green in spectrometer field of view
WG	Wet weight of grass	T1 - T6	Reflectance factor in thematic mapper bands 1 through 6.

Table 10a

***** CORRELATION MATRIX *****

VAR.															
WTOT	1.0000														
WGFS	0.8706	1.0000													
WLC	0.9365	0.6427	1.0000												
WL	0.9410	0.6971	0.9683	1.0000											
WC	0.7406	0.4051	0.8645	0.7116	1.0000										
WG	0.8164	0.7351	0.7472	0.7273	0.6382	1.0000									
WF	0.5036	0.7245	0.2677	0.3692	0.0100	0.1552	1.0000								
SLM12	0.5436	0.5201	0.4756	0.5273	0.2767	0.4829	0.3763	1.0000							
PV	0.1533	0.3331	0.0013	0.0727	-0.1427	0.2605	0.2559	0.3374	1.0000						
T1	-0.5086	-0.5813	-0.3775	-0.4008	-0.2554	-0.6118	-0.2576	-0.3964	-0.6296	1.0000					
T2	-0.4708	-0.5106	-0.3691	-0.4040	-0.2252	-0.4930	-0.2542	-0.3792	-0.5761	0.9571	1.0000				
T3	-0.5404	-0.6216	-0.3984	-0.4217	-0.2721	-0.6287	-0.3347	-0.3697	-0.6046	0.9813	0.9309	1.0000			
T4	0.2308	0.3470	0.1120	0.0626	0.1891	0.3652	0.2608	0.0208	0.0971	-0.1832	0.0501	-0.2883	1.0000		
T5	-0.5929	-0.6068	-0.4907	-0.5326	-0.3086	-0.4457	-0.4702	-0.6305	-0.4953	0.7230	0.7962	0.7084	0.2130	1.0000	
T6	-0.6084	-0.6716	-0.4686	-0.4990	-0.3141	-0.5361	-0.4884	-0.6196	-0.5710	0.8185	0.8282	0.8190	-0.0182	0.9655	1.0000
	WTOT	WGFS	WLC	WL	WC	WG	WF	SLM12	PV	T1	T2	T3	T4	T5	T6

WTOT Total wet weight of biomass

WGFS Wet weight of green biomass (grass, forbs, and shrubs)

WLC Wet weight of brown biomass (litter and carryover)

WG Wet weight of grass

WF Wet weight of forbs

SLM12 Average soil moisture at the depth (2 cm and 15 cm)

PV Visual estimate of percent green in spectrometer field of view

T1 - T6 Reflectance factor in thematic mapper bands 1 through 6

WL Wet weight of litter

WC Wet weight of carryover.

Table 10b

***** CORRELATION MATRIX *****

VAR.	WTOT	WGFS	WLC	WL	WC	WG	WF	SLM12	PV	T1	T2	T3	T4	T5	T6
WTOT	1.0000														
WGFS	0.8373	1.0000													
WLC	0.9836	0.7250	1.0000												
WL	0.9775	0.7383	0.9879	1.0000											
WC	0.9369	0.6595	0.9628	0.9093	1.0000										
WG	0.9252	0.9068	0.8665	0.8882	0.7782	1.0000									
WF	0.2286	0.6457	0.0751	0.0856	0.0523	0.2824	1.0000								
SLM12	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000							
PV	0.0495	0.2936	-0.0345	-0.0310	-0.0385	0.0995	0.5031	0.0000	1.0000						
T1	-0.2368	-0.3278	-0.1902	-0.2261	-0.1165	-0.1869	-0.4476	-0.0015	-0.6186	1.0000					
T2	-0.1419	-0.2371	-0.1006	-0.1351	-0.0346	-0.0763	-0.4478	-0.0010	-0.6025	0.9828	1.0000				
T3	-0.2300	-0.3024	-0.1900	-0.2251	-0.1176	-0.1703	-0.4375	0.0010	-0.6324	0.9905	0.9840	1.0000			
T4	0.1233	-0.1219	0.1955	0.1578	0.2497	0.0302	-0.4151	0.0000	-0.1297	0.4982	0.5629	0.4738	1.0000		
T5	-0.4058	-0.5403	-0.3330	-0.3491	-0.2856	-0.4179	-0.5517	-0.0039	-0.5767	0.8389	0.8193	0.8472	0.6196	1.0000	
T6	-0.5131	-0.6386	-0.4358	-0.4031	-0.4674	-0.5647	-0.4766	0.0010	-0.1883	0.3823	0.3466	0.3820	0.5053	0.7595	1.0000

WTOT Total wet weight of biomass

WGFS Wet weight of green biomass (grass, forbs, and shrubs)

WLC Wet weight of brown biomass (litter and carryover)

WG Wet weight of grass

WF Wet weight of forbs

SLM12 Average soil moisture at the depth (2 cm and 15 cm)

PV Visual estimate of percent green in spectrometer field of view

T1 - T6 Reflectance factor in thematic mapper bands 1 through 6

WL Wet weight of litter

WC Wet weight of carryover.

Table 10c

***** CORRELATION MATRIX *****

VAR.	WTOT	WGFS	WLC	WL	WC	WG	WF	SLM12	PV	T1	T2	T3	T4	T5	T6
WTOT	1.0000														
WGFS	0.6790	1.0000													
WLC	0.9874	0.5541	1.0000												
WL	0.9849	0.5649	0.9948	1.0000											
WC	0.6819	0.2977	0.7089	0.6337	1.0000										
WG	0.7612	0.9109	0.6665	0.6786	0.3644	1.0000									
WF	-0.1226	0.2657	-0.1964	-0.2122	-0.0228	-0.1206	1.0000								
SLM12	0.4262	0.1688	0.4466	0.4050	0.5913	0.3455	-0.2959	1.0000							
PV	-0.6779	-0.1300	-0.7406	-0.7251	-0.6063	-0.2744	0.2124	-0.3462	1.0000						
T1	0.4488	0.1173	0.4836	0.4881	0.2948	0.1679	-0.0980	-0.0862	-0.3009	1.0000					
T2	0.4042	0.0902	0.4388	0.4387	0.2965	0.1708	-0.1912	-0.0008	-0.2201	0.9759	1.0000				
T3	0.5999	0.1907	0.6391	0.6332	0.4710	0.2961	-0.2247	0.1209	-0.4219	0.9602	0.9625	1.0000			
T4	-0.3427	-0.1925	-0.3470	-0.3352	-0.3159	-0.2614	-0.0137	-0.3606	0.5298	0.3999	0.5069	0.3051	1.0000		
T5	-0.4528	-0.5292	-0.3992	-0.3788	-0.4109	-0.5486	-0.1671	-0.4873	0.3625	0.2422	0.2786	0.1306	0.7209	1.0000	
T6	-0.4477	-0.5475	-0.3895	-0.3600	-0.4666	-0.5695	-0.1324	-0.6108	0.2917	0.2583	0.2497	0.1189	0.6151	0.9675	1.0000

WTOT Total wet weight of biomass

WGFS Wet weight of green biomass (grass, forbs, and shrubs)

WLC Wet weight of brown biomass (litter and carryover)

WG Wet weight of grass

WF Wet weight of forbs

SLM12 Average soil moisture at the depth (2 cm and 15 cm)

PV Visual estimate of percent green in spectrometer field of view

T1 - T6 Reflectance factor in thematic mapper bands 1 through 6

WL Wet weight of litter

WC Wet weight of carryover.

Table 10d

Table 11

Coefficients of Determination for Little Bow
(optical measurements made with ground spectrometer)

Month	Parameter	Units	min	max	Number of samples	r^2 for TM Band 3	4	5	6
June	plant moisture	%	22	60	24	.1	.0	.1	.0
	biomass	kg/ha							
	grass	"	0	3000	27	.4	.0	.1	.1
	forbs	"	0	4000	27	.2	(+).2	.0	.0
	grass + forbs	"	180	5400	27	.5*	.0	.1	.1
	litter + carryover	"	80	3200	27	.1	.1	.0	.0
	total	"	350	6100	24	.3	.0	.0	.1
July	plant moisture	%	10	50	45	.1	(+).2	.0	.0
	biomass	kg/ha							
	grass	"	0	4300	45	.6**	.0	.4*	.4*
	forbs	"	0	4700	45	.4	(+).2	.3	.3
	grass + forbs	"	0	6000	45	.8**	.0	.5**	.6**
	litter + carryover	"	0	3600	45	.3	.0	.1	.1
	total	"	0	8800	45	.8**	.0	.4*	.4*
August	plant moisture	%	25	50	16	.1	.0	.0	.1
	biomass	kg/ha							
	grass	"	220	1450	23	.1	.1	.3	.5*
	forbs	"	0	850	23	.0	(+).2	.0	.0
	grass + forbs	"	400	1750	23	.2	.0	.3	.5*
	litter	"	0	1000	23	.3	.2	.5*	.3
	carryover	"	0	1000	20	.2	.3	.5*	.5*
	litter + carryover	"	0	2000	20	.2	.3	.5*	.5*
	total	"	500	3500	19	.3	(+).2	.3	.5*
Sept.	plant moisture	%	0	100	27	.3	.0	.2	.3
	biomass	kg/ha							
	grass	"	100	3400	33	.1	.0	.2	.3
	forbs	"	0	2200	33	.1	(+).1	.1	.0
	grass + forbs	"	100	3400	33	.2	.0	.3	.2
	litter	"	0	900	32	.2	.0	.1	.3
	carryover	"	0	300	33	.0	.0	.0	(+).1
	litter + carryover	"	70	1200	32	.1	.0	.2	.2
	total	"	500	4500	29	.2	.0	.3	.4*

* Significant at the 5% level
** Significant at the 1% level

Table 12

Coefficients of Determination for Ross Lake
(optical measurements made with ground spectrometer)

Month	Parameter	Units	min	max	number of samples	r^2 for TM band 3	4	5	6
June	plant moisture	%	25	75	9	.5	.2	.6	.0
	biomass	kg/ha							
	grass	"	0	4000	9	(+).2	(+).3	(+).4	(+).2
	forbs	"	0	2500	9	.7*	.2	.7*	.6
	grass + forbs	"	1500	4200	9	(+).0	(+).2	.0	.0
	litter + carryover	"	0	9200	9	(+).4	(+).3	(+).5	(+).3
	total	"	1700	7400	8	(+).6*	(+).1	(+).8*	(+).8*
July	plant moisture	%	0	55	22	.6**	(+).6**	.1	-.0
	biomass	kg/ha							
	grass		0	5200	27	.2	(+).1	.4*	(+).2
	forbs	"	0	5500	27	.3	(+).5**	.0	.0
	grass + forbs	"	0	6500	27	.6**	(+).4*	.3	.5**
	litter	"	0	2500	27	.0	.0	.2	.4*
	carryover	"	0	1700	27	.0	.0	.2	.4*
	litter + carryover	"	0	3700	27	.0	.0	.2	.4*
	total	"	0	10000	27	.3	(+).2	.3	.6**
August	plant moisture	%	23	55	20	.0	.0	.0	(+).2
	biomass	kg/ha							
	grass	"	350	4000	21	.0	.0	.3	.4
	forbs	"	0	1800	21	.0	.0	.1	.1
	grass + forbs	"	1000	4500	21	.0	.0	.4	.6**
	litter	"	0	5000	21	.0	.0	.2	.2
	carryover	"	0	3200	21	.0	(+).1	.3	.3
	litter + carryover	"	0	7500	21	.0	.0	.3	.3
	total	"	750	9000	21	.0	(+).1	.3	.4
Sept	plant moisture	%	0	50	21	.1	(+).1	.3	.1
	biomass	kg/ha							
	grass	"	100	3200	21	.0	.1	.4	.5*
	forbs	"	0	1000	21	.1	.0	.0	.0
	grass + forbs	"	500	3200	21	.0	.1	.5	.6**
	litter	"	0	1700	21	.0	.1	.3	.3
	carryover	"	0	1400	21	.0	.2	.5	.5*
	litter + carryover	"	6	3000	21	.0	.2	.4	.5*
	total	"	750	5700	21	.1	.1	.5	.6**

* Significant at the 5% level
** Significant at the 1% level

Table 13

Coefficients of Determination for Stavely
(optical measurements made with ground spectrometer)

Month	Parameter	Units	min	max	number of samples	r^2 for TM band 3	4	5	6
June	plant moisture	%	30	95	24	.0	.2	.0	.0
	biomass	kg/ha							
	grass	"	90	3000	24	.0	.1	.2	.0
	forbs	"	0	4400	24	.4*	(+).2	.3	.3
	grass + forbs	"	450	6000	24	.2	.0	.6**	.4*
	litter + carryover	"	50	9000	24	(+).1	(+).2	.0	(+).1
	total	"	650	8500	24	.0	.1	.4*	.0
July	plant moisture	%	0	50	24	.2	(+).1	.2	.3
	biomass	kg/ha							
	grass	"	160	6000	30	.4*	(+).1	.2	.3
	forbs	"	0	5500	30	.1	(+).1	.2	.2
	grass + forbs	"	460	7500	29	.4*	(+).3	.3	.4*
	litter	"	0	7000	30	.2	.0	.3	.2
	carryover	"	0	4500	30	.1	.0	.1	.1
	litter + carryover	"	0	10000	28	.2	.0	.2	.2
	total	"	300	4000	24	.4*	(+).1	.3	.4*
August	plant moisture	%	0	75	15	.0	.2	.1	.0
	biomass	kg/ha							
	grass	"	150	5000	21	.0	.0	.2	.3
	forbs	"	40	4000	21	.2	.2	.3	.2
	grass + forbs	"	500	6000	21	.1	.0	.3	.4
	litter	"	0	9000	20	.0	.0	.0	.2
	carryover	"	0	8000	21	.0	(+).1	.1	.2
	litter + carryover	"	0	8200	17	.0	.2	.2	.6*
	total	"	500	8200	15	.1	.6*	.4	.7**
Sept	plant moisture	%	15	60	22	.1	.0	.0	(+).0
	biomass	kg/ha							
	grass	"	190	4000	24	(+).1	.1	.3	.3
	forbs	"	0	1000	21	.1	.0	.0	.0
	grass + forbs	"	200	4200	24	.0	.1	.4*	.4*
	litter	"	0	9500	22	(+).5*	.1	.1	.1
	carryover	"	0	1800	24	(+).2	.1	.2	.2
	litter + carryover	"	0	7500	21	(+).4*	.1	.2	.3
	total	"	0	8700	20	(+).3	.0	(+).3	.3

* Significant at the 5% level
** Significant at the 1% level

Table 14
Coefficients of Determination for Little Bow
(optical measurements from Landsat MSS)

Transect Date	Landsat Date	Type of Biomass	Number of samples	r^2 for MSS band 4	5	7
June	June 29	grass	9	(+).09	(+).12	(+).04
		forbs		.25	.05	.26
		litter &		.11	.00	.16
		carryover		.04	(+).03	.06
		total				
July	June 29	grass	7	.00	.02	.20
		forbs		.00	.06	.03
		litter &		.16	.11	.64
		carryover		.06	.08	.46
		total				
July	July 8	grass	7	.02	.03	.09
		forbs		.02	.04	.01
		litter &		.33	.36	.42
		carryover		.16	.19	.23
		total				
July	July 26	grass	7	.17	.26	.33
		forbs		.01	.02	.02
		litter &		.50	.59	.75*
		carryover		.30	.39	.49
		total				
Sept	Sept 26	grass	5	.22	.16	.08
		forbs		(+).59	(+).38	(+).21
		litter &		.05	.43	.67*
		carryover		(+).00	.17	.40
		total				

* Significant at the 5% level

Table 15
Coefficients of Determination for Ross Lake
(optical measurements from Landsat MSS)

Transect Date	Landsat Date	Type of Biomass	Number of samples	r^2 for MSS band 4	5	7
June	July 06	grass	5	.89*	.85*	.58
		forbs		.48	.15	.00
		shrubs		(+).26	(+).15	.72
		litter		.88*	.93*	(+).72
		total		.92*	.89*	(+).61
July	July 26	grass	5	.91**	.96**	(+).71
		forbs		.05	.09	(+).04
		shrubs		(+).23	(+).42	.64
		litter		.86*	.97**	(+).85*
		total		.88*	.96**	(+).75
Sept	Sept 09	grass	5	(+).79	(+).74	.61
		forbs		(+).66	(+).42	.88*
		shrubs		(+).37	(+).00	.14
		litter		(+).80	(+).77	.57
		total		(+).81	(+).76	.60
June	July 06	grass	6	.85*	.79	(+).59
		forbs		.32	.03	(+).02
		shrubs		(+).25	(+).65	.49
		litter		.70	.88*	(+).69
		total		.71	.90*	(+).63

* Significant at the 5% level
** Significant at the 1% level

Table 16
Coefficients of Determination for Stavely
(optical measurements from Landsat MSS)

Transect Date	Landsat Date	Type of Biomass	Number of samples	r^2 for MSS band 4	5	7
June	June 21	grass	10	.04	.01	.00
		forbs		(+).01	(+).01	(+).02
		shrubs		.27	.10	(+).27
		litter		(+).01	(+).01	.00
		total		.03	.00	(+).03
July	July 27	grass	7	.40	.70	(+).01
		forbs		(+).04	(+).00	(+).48
		shrubs		.00	.00	(+).24
		litter		.00	.19	.01
		total		.04	.34	(+).00

TABLE 17

SUMMARY OF GROUND MEASUREMENTS[1]
JUNE - OCTOBER, 1980
ROSS LAKE

Sampling Period	Transect No.	Range Condition (subjective assessment)	Biomass in kg/ha (dry weight)					% ground surface covered by		
			Green			Litter/ C-O	Total	Green Vegetation	Litter & Carryover	Bare Soil
			Grass	Forbs	Shrubs					
June	1	Fair	543	168	70	645	1309	56	42	3
	2	Fair	548	233	28	504	1312	57	38	7
	3	Fair	441	199	32	576	1248	52	41	6
	4	Fair	500	234	56	323	1113	53	39	8
	5	Excellent	1004	172	2	2166	3344	52	47	1
	6	Excellent	1230	292	47	2344	3539	43	57	1
July	1	Fair	659	340	86	712	1797	74	24	5
	2	Fair	822	226	240	758	2046	75	23	2
	3	Fair	654	194	24	1008	1880	75	20	5
	4	Fair	673	446	44	697	1860	75	25	1
	6	Excellent	1689	425	38	2689	4841	71	30	0
August	1-4	Fair	440	290	200	163	1093	56	40	5
	6	Excellent	1840	273	0	1787	3900	58	43	0
September	1	Fair	279	105	48	437	869	32	61	6
	2	Fair	229	82	10	293	614	22	61	17
	3	Fair	293	36	30	585	944	32	56	14
	6	Excellent	999	30	0	2730	3784			
October	1	Fair	822 (includes forbs)			562	1384	NOT MEASURED		
	4	Fair	510 (includes forbs)			220	730			

[1]mean of quadrats 1 m^2 (10 quadrats per transect)

TABLE 18

SUMMARY OF GROUND MEASUREMENTS[1]
JUNE - OCTOBER, 1980
S T A V E L Y

Sampling Period	Transect No.	Range Condition (subjective assessment)	Biomass in kg/ha (dry weight)					% ground surface covered by		
			Green			Litter/ C-O	Total	Green Vegetation[2]	Litter & Carryover	Bare Soil
			Grass	Forbs	Shrubs					
June	A-1	Excellent	1234	559	150	3462	5846	58	43	1
	A-2	Excellent	1156	297	152	2314	3920	63	43	1
	B-2	Good-Fair	772	412	22	1076	2412	64	36	0
	C-1	Fair	534	483	39	547	1603	64	37	0
	C-2	Fair	355	323	72	802	1552	58	46	5
	D-1	Poor	149	298	22	98	567	63	31	7
	D-2	Poor	320	253	0	307	880	54	35	13
	D-3	Poor	320	427	0	667	1413	60	40	2
	E-1	Good	1348	212	9	1079	2648	73	27	0
	E-2	Good	843	611	118	1692	3331	65	35	0
July	A-1	Excellent	1212	414	58	2480	4164	68	33	1
	A-2	Excellent	1172	546	160	3042	4920	70	30	1
	B	Good-Fair	1352	426	252	1250	3780	64	36	0
	C-1	Fair	793	542	107	952	2394	56	46	0
	C-2	Fair	621	247	4	1288	2160	65	35	1
	D	Poor	99	153	16	74	342	49	36	16
	E-1	Good	1020	426	6	2576	4028	52	48	0
	E-2	Good	1498	212	0	2240	3950	48	47	5

Table 18 continued (Stavely)

Sampling Period	Transect No.	Range Condition	Biomass in kg/ha (dry weight)					% ground surface covered by		
			Green			Litter/ C-O	Total	Green Vegetation[2]	Litter & Carryover	Bare Soil
			Grass	Forbs	Shrubs					
August	A	Excellent	1188	268	148	1800	3404	55	45	0
	B	Good-Fair	612	308	228	360	1508	--	--	-
	C	Fair	612	760	0	280	1652	70	30	0
	D	Poor	200	220	40	240	700	48	47	4
	E-1	Good	1028	612	0	1360	3000	53	47	0
September	A	Excellent	803	62	44	2068	2977	28	70	0
	B	Good-Fair	752	38	268	1682	2740	37	58	2
	C-1	Fair	514	33	62	1002	1611	32	68	0
	C-2	Fair	610	72	42	905	1629	42	59	0
	D	Poor	88	152	0	148	388	40	38	20
	E-1	Good	588	68	0	1128	1784	28	67	5
	E-2	Good	394	44	46	1840	2324	16	71	14
October	A	Excellent	946	216	0	3608	4770	N O T M E A S U R E D		
	D	Poor	120	370	0	0	490			

[1]Mean of quadrats 1 m^2 (10 quadrats per transect)

[2]Includes cover of little club moss